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Academician, Russian Academy of Sciences
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U-Pb Age and Correlation of Magmatic Rocks from Granulite and Amphibolite Complexes of the Volga–Ural Region, East European Platform

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Abstract – U-Pb dating has shown that in the Volga–Ural region, the magmatic rocks from granulite and amphibolite complexes forming the basement of the East European platform were generated mainly at the end of the Archean. Comparable age values (2738 ± 11 Ma, 2725 ± 42 Ma, and 2709 ± 16 Ma) were measured in enderbites of different types from various localities of the region. Diorites of the Bakaly granitoid massif have an age of 2698 ± 12 Ma. This data suggests that endogeneous rocks in the studied region were formed during a narrow interval of time.

In the Volga–Ural region, the basement of the East European platform was recovered by drill holes at more than 6000 sites. The data obtained characterizes main metamorphic and magmatic complexes, their origin, and stages of formation (Bogdanova *et al.*, 1979; Bogdanova, 1986; Vasil'eva *et al.*, 1992). Still, the basement geochronology has so far been based mainly on the K-Ar age determinations with most values corresponding to the period of 2.5 - 1.6 Ga (Garris, 1977). There have been only a few determinations by the Rb-Sr and U-Pb methods (Bibikova *et al.*, 1984; Bogdanova *et al.*, 1979), and now we present new results of U-Pb dating to improve the stratigraphic subdivision and correlation of distant Early Precambrian formations. From a geological standpoint, the region under consideration is a part of a vast granulite-gneiss province, the larger portion of which (more than 50%) consists of granulite complexes untouched by superimposed alterations. The area of some of their blocks is up to a thousand km^2. The granulite blocks are surrounded, or complicated by diaphthorite and ultrametagenic zones of the amphibolite facies metamorphism affected by the granulite substratum (Vasil'eva *et al.*, 1992).

Direct petrographical observations along block margins revealed their various transitional rocks with paragenetic mineral sequences characteristic of different structural zones. Tectonic relations between the granulite and amphibolite formations suggest a basic structural reorganization. Linear folded structures of the granulite complex with an areal type of metamorphism grade into concentric zonal and dome structures of the amphibolite complex. According to this and general geological data, and by analogy with other granulite-gneiss provinces, the granulite complex was referred to the Archean, while the amphibolites were interpreted as Early Proterozoic rocks (Bogdanova *et al.*, 1986; Vasil'eva *et al.*, 1992).

Rocks of the Nurlat complex are dominant among granulite formations' being represented by alternating pyroxene and enderbite gneisses with members of lesser thickness consisting of amphibole-pyroxene schists. This complex forms linear folded structures of a northeastern strike. In addition, the granulite blocks include large massifs of typical enderbites with restricted zones of a gneissic texture (the Kolyvan' granitoid complex). The enderbite genesis is problematic, because they are assumed to be formed as follows: (1) as originally crustal rocks; (2) after the volcanic rocks as palingenetic formations of the early folding stage; and (3) as intrusive rocks of the late folding stage.

The Nurlat enderbite-schist complex is the best studied in the block of the same name located in southern Tatarstan at the junction zone of the South Tartar arch and the Melekess depression (Fig. 1). The block is about 60 km long, and nearly 20 km wide. Its rocks are recovered by many drill holes, five of which penetrated into the granulites down to nearly 600 m, thus being the reference sites. One of these drill holes (663 in the Ul'yanovsk district) revealed alternating members of pyroxene schists and enderbite gneisses, which represent a sequence of differentiated rocks of basic to acid chemical composition (Lapinskaya *et al.*, 1990). The thickness of schist members is up to 30 m, and they compose less than 10% of the section. Rocks of Site

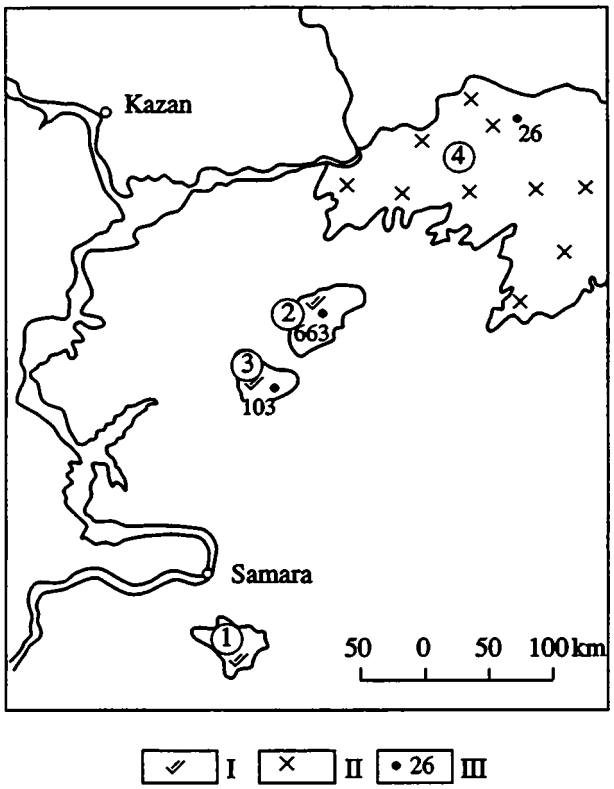

Fig. 1. Locations of studied subjects in the Volga–Ural region. 1 – Kolyvan' enderbite massif; 2 – Nurlat granulite block; 3 – Titovka granulite massif; 4 – Bakaly granitoid massif. I – rocks of enderbite type; II – microcline plagiogranites; III – Site number.

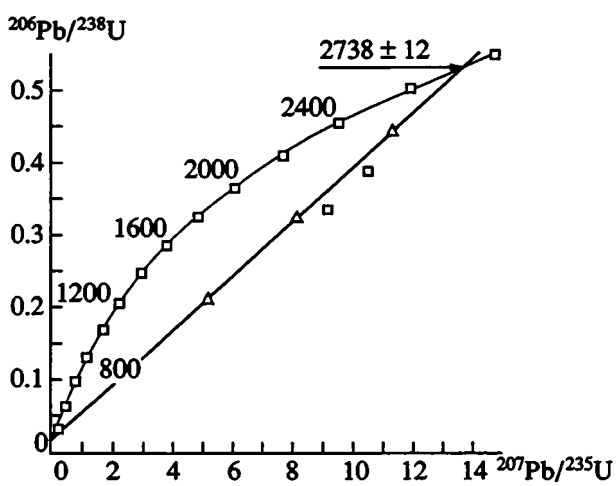

Fig. 2. Concordia diagram for zircons from charnockite rocks, the Kolyvan' massif.

663 are the least affected by the K-metasomatism (the rocks of charnockite type are absent) and by the diaphthoritic alterations.

We selected the garnet-bearing enderbite gneisses for isotopic geochronological analysis. These are grey, medium-grained rocks with ocellar to eutaxitic structures, and porphyrogranoblastic to linear-parallel texture. Their constituent minerals are as follows: antiperthite plagioclase An_{32-37} (50 - 60%), quartz (15 - 20%), potassium feldspar (up to 5%), hypersthene (15 - 20%), biotite (up to 10%), garnet (up to 5%), ore minerals (up to 5%), and accessory zircon and apatite. Zircon is represented by prismatic grains of magmatic origin. They are transparent or translucent, and have a brown color of a different intensity.

The Kolyvan' massif, located in the western part of the Buzuluk depression, Samara district (Fig. 1), is a typical and well studied enderbite massif. It is latitudinally elongated, and occupies an area of about 900 km^2. The massif boundaries are not defined very precisely because its marginal facies and the host rocks have similar mineralogy and structure. The massif consists of grey, medium- to coarse-grained, partly gneissic enderbites of the following mineral composition: antiperthite plagioclase An_{32-36} (55 - 65%), hypersthene (5 - 10%), amphibole (0 - 5%), biotite (1 - 2%), microperthite (15 - 25%), and quartz (20 - 30%). The accessory minerals of the rocks are apatite, zircon, monazite, rutile, and ilmenite. An essential part of the massif consists of charnockites with a microperthite content up to 45%. Besides, there are microperthite granites bearing up to 65% of potassium feldspar. The U-Pb data for magmatic zircons from the Kolyvan' massif was published earlier (Bibikova *et al.*, 1986). Recalculated by Ludwig's program (Ludwig, 1991), this data resulted in an age value of 2738 ± 11 Ma (Fig. 2).

Recently, in the Melekess depression of the Samara district (Fig. 1), a larger enderbite massif (the Titovka massif) 50 × 50 km in dimension was recovered by drilling at 40 sites. It consists of rocks remarkably monotonous in composition and structure. They represent a slightly differentiated series varying from melanocratic gabbro-anorthosites to leucocratic enderbites, or sometimes to charnockites. The rocks have a hypidiomorphic-granular texture and a massive structure of magmatic origin. Zones of gneissic structure are rare, mainly confined to the massif's marginal parts. In addition to enderbite and gabbro-anorthosites, some drill holes also recovered pyroxenites and massive charnockites. It is remarkable that rocks of basic composition, the gabbroids and schists characteristic of other large blocks, are entirely absent here. Diaphthorites occur in this massif sporadically, near the faults. The outer massif boundaries are distinctly mapped.

We studied the accessory zircons from enderbite of the Titovka massif (Site 103), where they are represented by well formed prismatic grains with smoothed contours, and lack inner cores.

Magmatic rocks of the amphibolite complex were selected for dating from the largest Bakaly granitoid massif that occupies an area of 14 000 km^2 in eastern Tatarstan and western Bashkortostan, where the eastern part of the South Tartar arch (Fig. 1) was drilled at more than 1500 sites. This massif consists of palingenetic granitoids of the polymigmatite series, which were

Table 1. U-Pb ages of zircons from rocks of enderbite type in the Volga–Ural region

Fraction size, μm	Concentration, ppm		Pb isotope composition			Isotopic ratios		Age, Ma
	Pb	U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
Nurlat granulite block, Ul'yanovsk area, Site 663								
−160 + 125	141	250	1799	0.1920	0.1071	12.7559	0.4995	2700
−125 + 100	283	512	2732	0.1883	0.1066	12.4821	0.4924	2688
−100 + 75	162	286	2247	0.1904	0.1150	12.8208	0.5026	2698
Titovka massif, area of the village of Titovka, Site 103								
−150 + 100 (Dark colored)	229	561	1685	0.1876	0.1310	8.8789	0.3572	2655
−150 + 100 (Light colored)	268	544	3750	0.1872	0.1207	11.0629	0.4362	2688
+150 (Dark colored)	90	220	895	0.1973	0.3187	7.5697	0.3086	2633

Note: Common leads are corrected for the model Pb of 2700 Ma (Stacey and Kramers, 1975).

Table 2. U-Pb ages of zircons from granitoids of the Bakaly massif, the Menzelinsk-Aktanysh area, Site 26

Fraction size, μm	Concentration, ppm		Pb isotope composition			Isotopic ratios		Age, Ma
	Pb	U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
+125 (Rose)	148	241	2488	0.1896	0.1380	12.1201	0.4757	2693
+125 (Gray)	168	347	1648	0.1896	0.1464	10.4550	0.4166	2671
−125 + 88 (Rose)	133	259	2342	0.1879	0.1269	11.3820	0.4520	2677
−125 + 88 (Gray)	163	377	1680	0.1887	0.1406	9.3709	0.3749	2664
−125 + 88 (Colorless)	123	261	4016	0.1856	0.1213	10.5331	0.4186	2676

Note: Common leads are corrected for the model Pb of 2700 Ma (Stacey and Kramers, 1975).

most likely melted out of heterogeneous folded formations of the granulite substratum. Its diaphthorite fragments are exposed in some parts of the massif, being abundant along the massif margins in the form of migmatite fields. Rocks of diorite-plagiogranite and granodiorite-granite series were recognized among the recovered granitoids. The last series generation completes the granitization processes in the eastern part of the Russian platform. Zircons from diorites of the Site 26, located in the Menzelinsk–Aktanysh area, were used for the U-Pb dating. The diorites are massive, medium-grained, with hypidiomorphic granitic texture. They consist of plagioclase An_{39-45} (50 - 55%), biotite (5 - 7%), amphibole (10 - 15%), quartz (15 - 25%), microcline (3 - 10%), and such accessory minerals as apatite, zircon, orthite, and sphene. In places, the rocks are silicified, and have secondary microcline.

Subidiomorphic prismatic (elongation 2 - 3) zircon grains from the selected rocks are transparent or translucent, and have a light grey to light rose color. Some of them have rims of the late mineral generation.

Zircon fractions, separated according to grain size and morphology, were analyzed for U-Pb isotopes using principles of T. Krogh's method (Krogh, 1973), which have been adopted by many laboratories. After the chromatographic extraction with AG 1 × 8 anionite, the U- and Pb-concentrations were measured by the isotope dilution technique using the mixed tracer $^{208}Pb + ^{235}U$. The accuracy of measurements is ±1% for concentrations of both elements. The Pb isotopic composition was analyzed by the Cameca TSN 206A using silica gel as the ion emitter. The Pb isotopic ratios were measured with an accuracy of ±0.1%. The Pb isotopic composition was estimated according to the standard decay constants. The isochrone parameters are calculated using K. Ludwig's program (Ludwig, 1991). The obtained results are presented in Tables 1 and 2, and illustrated in Figs. 3 - 5.

The isochrone age, estimated for zircons from enderbite gneisses of the Nurlat block, is 2725 ± 42 Ma (Table 1, Fig. 3). These zircons are highly concordant in their isotopic ages thus suggesting the minor role of superimposed processes, and the reliability of our results.

Ages of zircons from the Titovka massif are more discordant. Their age, estimated by discordia, is 2709 ± 42 Ma (Table 1, Fig. 4).

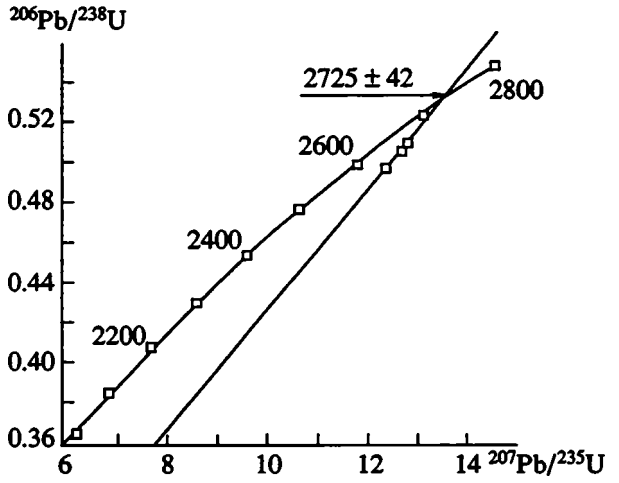

Fig. 3. Concordia diagram for zircons from enderbite rocks, the Nurlat granulite block.

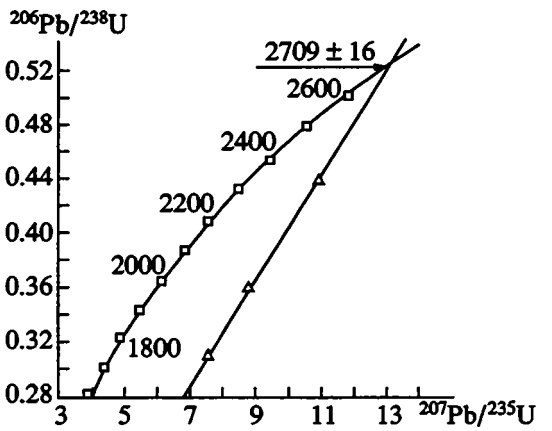

Fig. 4. Concordia diagram for zircons from enderbite of the Titovka massif.

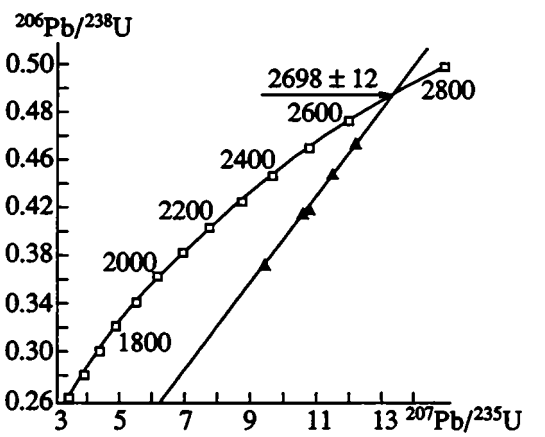

Fig. 5. Concordia diagram for zircons from diorite of the Bakaly massif.

The obtained age values should correspond to the formation time (magmatic crystallization) of enderbites because these rocks in both the Nurlat block and the Titovka massif contain zircons of a single generation with well defined discordia (MSWD ≤ 1). Therefore, the various enderbite types from different tectonic zones of the basement were formed in the Volga–Ural region during the Late Archean, in the period between 2700 and 2740 Ma. It is remarkable that the oldest values are obtained for rocks preserving some premetamorphic components. For example, two zircon fractions from the Kolyvan' massif (Bibikova *et al.*, 1984) plot to the right of discordia (Fig. 2), indicating the possible presence of older xenocrysts. This corresponds to the idea on the palingenetic origin of enderbites from the Kolyvan' complex. Premetamorphic features of the Nurlat complex are likely reflected in a certain stratification of the sequence that was interpreted to be a primary heterogeneity of the original volcanic rocks (Lapinskaya *et al.*, 1990). An emplacement of the Titovka massif seems to correspond to the stage of most intensive granitization, when the premetamorphic substratum was entirely homogenized. In particular, this may explain why the massif lacks zircon xenocrysts.

Therefore, the obtained age values suggest that enderbites of the Volga–Ural region were formed at the end of the Archean tectonomagmatic cycle as a result of the palingenesis of a "pregranulitic" substratum.

Zircons from diorites of the Bakaly massif, which was considered as Early Proterozoic like other formations of the amphibolite metamorphic complex, yielded the most remarkable results. According to the upper intersection of discordia and concordia, their age is 2698 ± 12 Ma, i.e., only 10 - 50 Ma younger than the age of the enderbites (Table 2, Fig. 5).

A small time span between the termination of the "granulitic stage" at the end of the Late Archean and the formation of palingenetic granitoids of the diorite-plagiogranite series shows that the regional stratigraphic scale of the Volga–Ural region (Lapinskaya *et al.*, 1985) needs to be revised. Using these results, we may assume that some subdivisions, referred to the Early Proterozoic, are in fact the Late Archean. Besides, the main magmatic and metamorphic complexes of the region were formed within a narrow interval of time. Thus, the former concept on the consolidation time of the basement of the East European platform requires certain corrections, and the intensity and history of the Early Proterozoic processes need clarification.

Reviewer I.V. Chernyshev.

REFERENCES

Bibikova, E.V., Bogdanova, S.V., Kirnozova, T.I., and Popova, L.P., U-Pb Age of Charnockite Type Rocks in the Volga–Ural Region, *Dokl. Akad. Nauk SSSR*, 1984, vol. 276, no. 4, pp. 916 - 917.

Bogdanova, S.V., *Zemnaya Kora Russkoi Plity v Rannem Dokembrii* (The Earth's Crust of Russian Platform in the Early Precambrian), Moscow: Nauka, 1986.

Bogdanova, S.V., Gorokhov, I.M., Krylov, I.N., *et al.*, Rb-Sr Age of Granulites in the Volga–Ural Region, *Dokl. Akad. Nauk SSSR*, 1979, vol. 244, no. 3, pp. 707 - 709.

Bogdanova, S.V., Lapinskaya, T.A., Popova, L.P., and Postnikov, A.V., Evolution of Endogenic Processes during the Earth's Crust Formation in the Volga–Ural Region, *Endogennye Rezhimy Formirovaniya Zemnoi Kory i Rudoobrasovaniya v Rannem Dokembrii* (Endogenic Regimes of the Earth's Crust Formation and Ore Genesis during the Early Precambrian), Leningrad: Nauka, 1985, pp. 214 - 217.

Garris, M.A., *Etapy Magmatizma i Metamopfizma v Doyurskoi Istorii Urala i Priural'ya* (Stages of Magmatism and Metamorphism in the pre-Jurassic History of the Urals and Adjacent Regions), Moscow: Nauka, 1977.

Krogh, T.E., A Low Contamination Method for Hydrothermal Decomposition of Zircons and Extraction of U and Pb for Isotope Age Determination, *Geochim. et Cosmochim. Acta*, 1973, vol. 37, pp. 485 - 495.

Lapinskaya, T.A., Popova, L.P., Postnikov, A.V., and Yakovlev, D.O., New Data on the Early Precambrian Magmatic Formations in the Eastern Part of the Russian Platform as Inferred from Deep Drilling, *Geologiya i Geokhronologiya Dokembriya Vostochno-Evropeiskoi Platformy* (Geology and Geochronology of the Precambrian in the East European Platform), Leningrad: Nauka, 1990, pp. 166 - 175.

Ludwig, K.R., ISOPLOT Program, *USA Geol. Surv., Open-File Rep. 91*, 1991.

Stacey, J.S., and Kramers, J.D., Approximation of Terrestrial Lead Isotope Evolution by Two-Stage Model, *Earth and Planet. Sci. Lett.*, 1975, vol. 26, pp. 207 - 221.

Vasil'eva, M.Yu., Zhuravlev, E.G., Knyazev, V.S., *et al.*, *Doplatformennye Komplelksy Neftegazonosnykh Territorii SSSR* ("Preplatform" Complexes of Oil and Gas Bearing Provinces of the USSR), Moscow: Nedra,1992.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 206 - 215. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 8 - 17.
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Evolution of the biosphere

Ecological Peculiarities of the Vendian–Cambrian Hyolithids Fauna in the Siberian Platform

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Abstract – The article presents a brief review of new data on the biostratigraphy of Vendian–Cambrian deposits in the Siberian Platform. It is proved that at that time a large evaporite basin, separated from the open sea by a relative uplift in the floor relief, had already begun to form in its territory. Specific features of the region paleogeography and chemical composition of sea water, particularly, the P_2O_5 content, had much greater influence on the composition of fossil assemblages and their distribution areas in Vendian–Cambrian time than they later had. This was due to the fact that the biomineralization process of an essentially organic Metazoa skeleton occurred only at the beginning.

The Precambrian–Cambrian boundary stratotype accepted now in Newfoundland, and the principle of its substantiation, based on the sequential assemblages of ichnofauna, exclude the possibility to determine, even in a general form, the level of this boundary in Siberia. Here, as everywhere else, the Cambrian lower boundary is defined by the appearance of certain groups of skeletal fauna.

Owing to the specific rock composition, mostly of carbonate composition, ichnofauna is practically absent in the Siberian sections. Therefore, we should broaden the Vendian–Cambrian interval, usually treated as a thin transitional member, by including in it the upper part of the definitely established Vendian located below it, i.e., beds with Ediacarian fauna (the Ediacarian proper or the Ediacarian stage) containing the most ancient pre-Tommotian fossils (the Nemakit–Daldyn Stage), and at least the *Nochoroicyathus sunnaginicus* zone, the oldest one in the definitely established Tommotian Stage. We can not limit the Vendian–Cambrian interval only to beds with skeletal fauna remains, as the lower boundary of the Nemakit–Daldyn unit is not at all defined, and was recently shifted, step by step, down to a more ancient strata (Khomentovskii and Karlova, 1992). Certainly, such an extensive and indefinite interval in the stratigraphic scheme of Siberia cannot be admitted. Therefore, until information substantiating the position of the boundary in the Siberian sections, coeval with the Vendian–Cambrian boundary stratotype in Newfoundland, is established we have to regard the base of the Tommotian Stage here as the base of the Cambrian, just as it was decided at late All-Union (All-Russian) conferences, where the problem was discussed (*Resheniya* ..., 1983, 1989).

In Siberia, the Vendian–Cambrian deposits with ancient fossil assemblages are most completely represented in the eastern part of the Siberian platform. Recently, some of our publications were devoted to describing key sections of the deposits (Fig. 1), their paleontological characteristics (Fig. 3), and correlations between them (Figs. 4, 5) (Khomentovskii and Karlova, 1992; 1993). Some comments for readers unfamiliar with these publications follow.

The *sunnaginicus* Zone of the Tommotian Stage and the *Purella antiqua* and *Anabarites trisulcatus* zones of the Nemakit–Daldyn Stage are chronostratigraphic subdivisions, in which the composition of fossil assemblages vary in different facies provinces of Siberia. Their synchronicity is proven by combined paleontological and lithostratigraphic data on a continuous series of well exposed sections linking the transitional and eastern facies regions in the southeastern part of the Siberian Platform (Fig. 1). The Upper Vendian Ust' Yudoma Formation, being essentially of dolomite composition, clearly consists here of four rhythmic members, well expressed in the slope reliefs.[1] Such markers control the biostratigraphic correlation.

[1] Each member is mainly composed of dolomites; their basal layers are rather thin and made up of terrigenous and terrigenous-carbonate rocks.

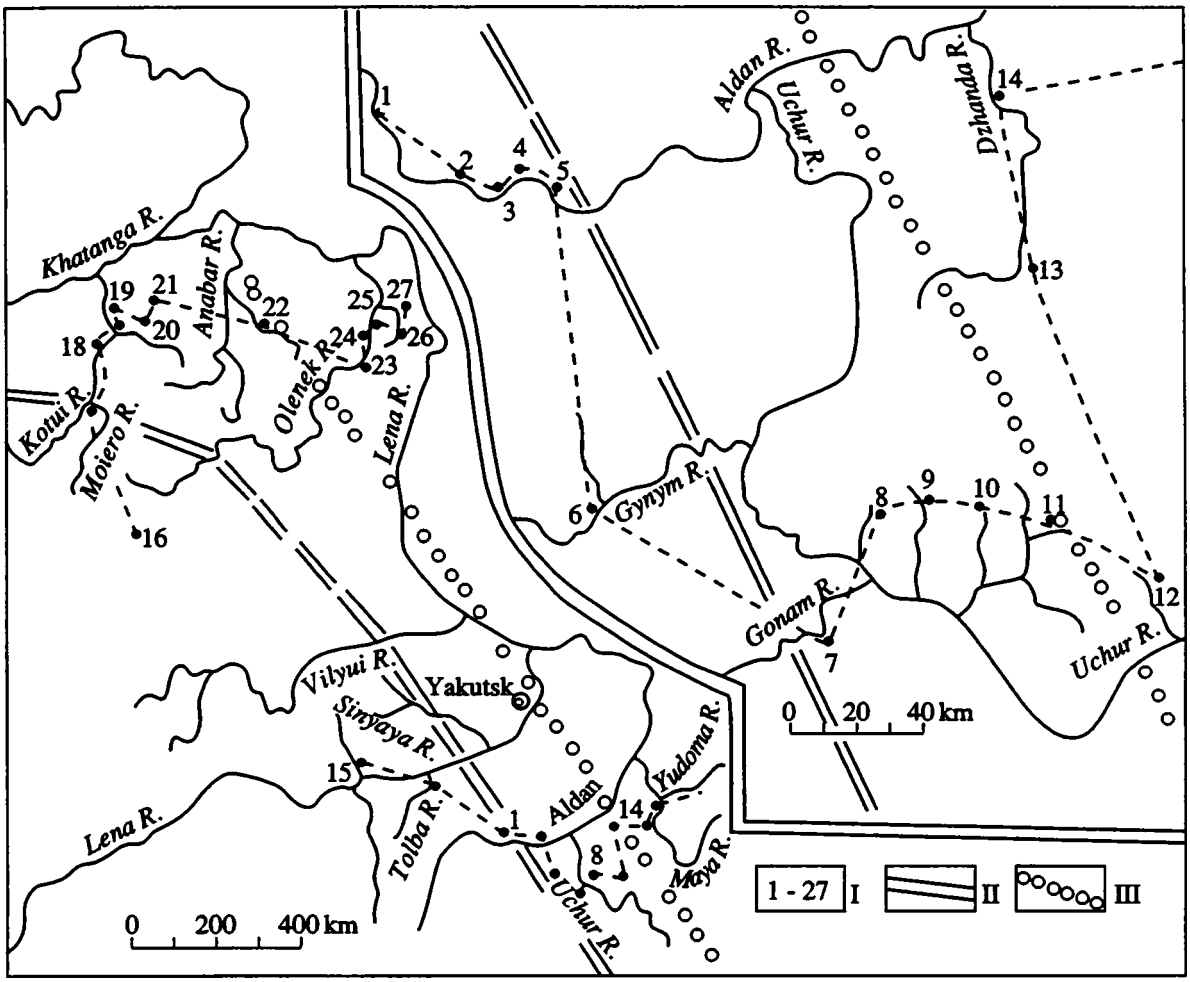

Fig. 1. Location scheme of key sections and paleontologic profiles.

I – Key sections (1 - 27): 1 – village of Ugino, 2 – Dvortsy, 3 – Vas'kina protoka, 4 – Byuktelekh, 5 – Ulakhan-Sulugur, 6 – Gynym R. near the mouth of Yalbyn Creek, 7 – Gonam R., height 1291.0, 8 – outflow of Berdyakit R., 9 – outflow of Chagdala R., 10 – Konus Mt. area, 11 – Nemnekei R., 12 – Selinde R., 13 – Dzhanka R. upper stream, 14 – Dzhanka R. lower stream, 15 – Namany R., mouth area, 16 – village of Aikhal, 17 – Moiero R. mouth area, 18 -19 – Kotui R. from Sergei–Koril–Uoran rapids up to Chomn–Yuryakh (Odikhincha), 20 – Medvezh'ya R. upper stream, 21 – Fomich R., 22 – Udzha R., 23 – Kyutingde R., 24 - 25 – Olenek R. from Borulakh Island up to Suordakh R., mouth, and 26 - 27 – Khorbusuonka R. from Anabyl R. mouth to Mattaiya R. mouth; II – axial part of the uplift of the Tommotian time; III – axial part of the arch of the Upper Vendian time.

Fossil assemblages enable us to reliably correlate northern sections of the Olenek and Anabar uplifts with the eastern sections of the southern Siberian Platform (Figs. 1, 2, 3), and both can be correlated to the stratigraphic scheme, elaborated on the basis of deep drilling data in the inner part of the platform between them (Khomentovskii and Karlova, 1992).

To understand the causes of significant change in the composition of the fossil assemblages in the transitional and eastern facies zones (Fig. 3), we need to decipher the specific features of the sedimentation environments in the mentioned paleostructures.

A general concept on the Lower Cambrian paleogeography in the Siberian Platform was formed in the 1950 - 60s, when it was suggested that an extensive evaporite basin (western facies area) was separated from an open sea of normal salinity (eastern facies area) by a system of uplifts (transitional facies zone). However, the observed similarity between the Vendian–Cambrian deposits of the transitional and eastern facies zones made it difficult to apply the described model.

Almost all over the Siberian Platform the Upper Vendian deposits consist of gray dolomites. However, in the west, anhydrite-bearing rocks, interlayers of anhydrite, gypsum, and salt are also encountered. So, a salt-forming basin was already formed there, its intense subsidence being compensated by chemogenic sedimentation.

In the Aldan River middle stream and Uchur-Aldan watershed the thickness of dolomites is reduced 2 to 3 times (Fig. 4). They show numerous signs of shoal origin: bird's eye structures, cross bedding, ripple marks, shoal breccias, and abundant phytolites, including large oncoids and columnar stromatolites. And,

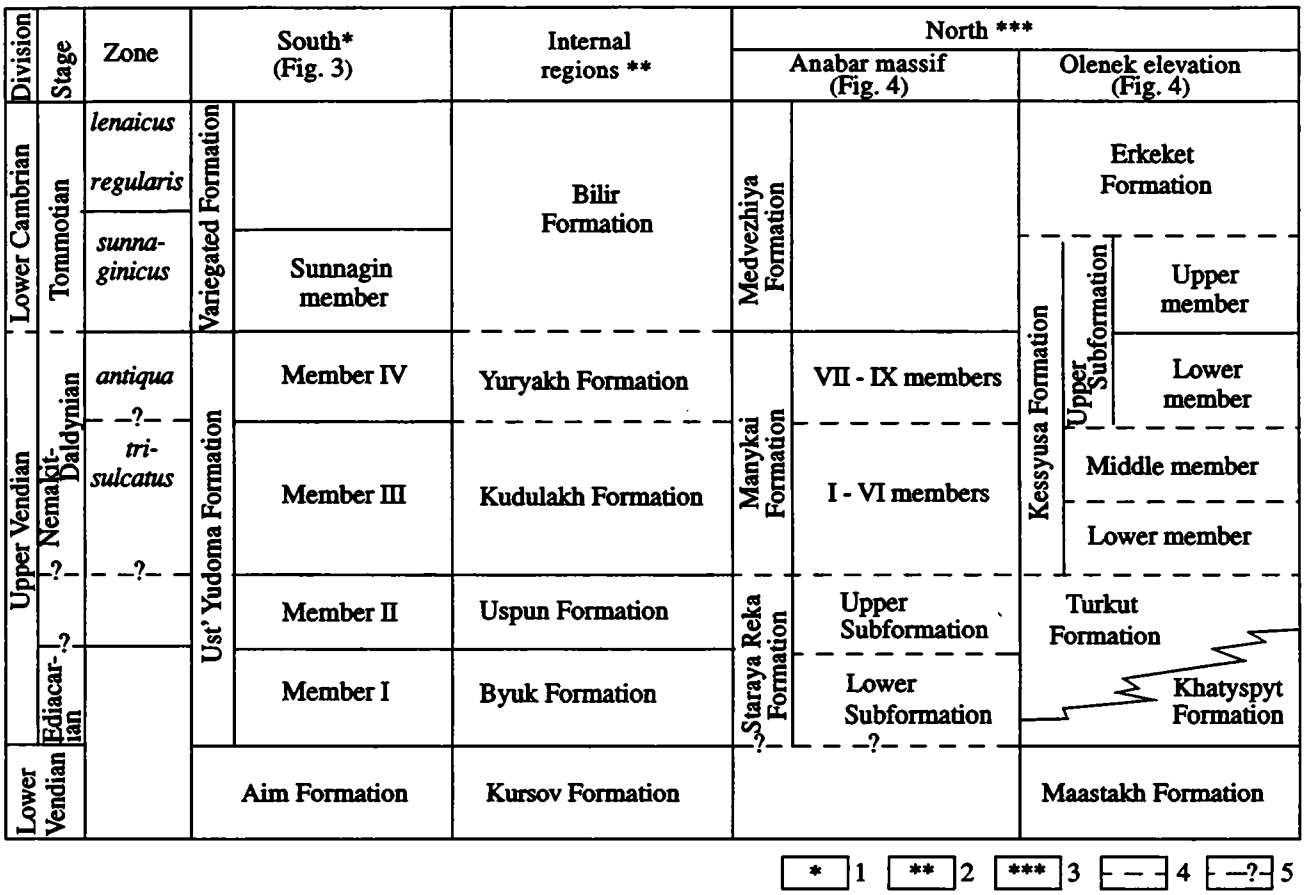

Fig. 2. Correlation scheme for composite sections of the Vendian–Cambrian deposits in the Siberian Platform.

1 - 3 – Compiled on data from: 1 – Khomentovskii and Karlova, 1992, 2 – *Resheniya* ..., 1989; 3 – Khomentovskii and Karlova, 1992, Khomentovskii, 1990, 4 – correlation with units of general and regional scales is doubtful, and 5 – exact position of the boundary in the local scale is unclear.

finally, in the eastern part of the Uchur plateau and in the Yudoma–Maya depression, the thickness of the Ust' Yudoma Formation again increases. The formation is characterized here by the appearance of limestones. The thickness of their members reaches 100 m. But in all lateral directions limestones are replaced by dolomites for a distance of several km, which is most likely due to dolomitization. Initially the amount of limestones in the eastern facies zone was much greater. Thus, a large, gently sloping arch existed in the Upper Vendian time in the southeastern Siberian platform. It distinctly separated the sinking basins. Clear signs of evaporite sedimentation in the west and limestone deposition in the east were observed (Fig. 4). The arch ridge was confined to the Omnya elevation.

The distribution of fossils corresponds to the described paleogeography. From analogs of the Ust' Yudoma Formation in western sections they are unknown. Only rare *Chancelloria* and Circotecidae are recorded in the western part of the arch base (the Timpton River mouth) within the upper 5 m of the formation. To the east (Dvortsy locality), *Chancelloria* and *Cambrotubulus* are encountered at the base of Member III (the *trisulcatus* Zone), and *Hyolithellus* was also discovered in lowermost parts of Member IV (Figs. 1, 3). Further to the east (near the Gonam River mouth) hyolithids were discovered: *Ladatheca annae* (Sys.), *Loculitheca anulata* Sys., the mollusks *Purella antiqua* (Ab.), *Barskovia* sp., *Igorella*, *Latouchella*, *Algomiella*, as well as *Helcionella* and *Aldanolina magna* Pelm., compose a representative assemblage of the *antiqua* Zone. Still further to the east (Mt. Konus) a more diverse molluscan assemblage includes the Chinese forms *Siphogonuchites triangularis* Qian, *Halkieria longa* (Qian.), *Archaeospira regularis* (Yiang) and others. The forms, known only in the eastern part, various *Protohertzines* and *Anabarites*, appeared near the arch ridge (the Nemnekei River) in the *trisulcatus* Zone. The Dzhanda River deposits near the eastern part of the arch slope base are dominated by eastern forms (Fig. 3).

An uplift, analogous to that in the south, is traced in the northern Siberian Platform (Fig. 5). During the Vendian time, its crest was found located within the Anabar massif, where relevant deposits (the Staraya River Formation) are much thinner than the evaporite sediments recovered by deep boreholes in the more western sections. East of them, at the Olenek uplift, the thickness

Fig. 3. Distribution of hyolithids fauna in key sections of the Vendian–Cambrian deposits in the Siberian Platform (from Khomentovskii and Karlova, 1993, with more precise definitions).

1 – transitional facies area; 2 - 5 – sections: 2 – Aldan R., 3 – Gonam R., 4 – Mt. Konus, 5 – Nemnekei R., and 6 – eastern facies zone; 7 - 10 – sections: 7 – Selinda R., 8 – Dzhanda R., 9 – eastern Anabar region, 10 – Olenek uplift.

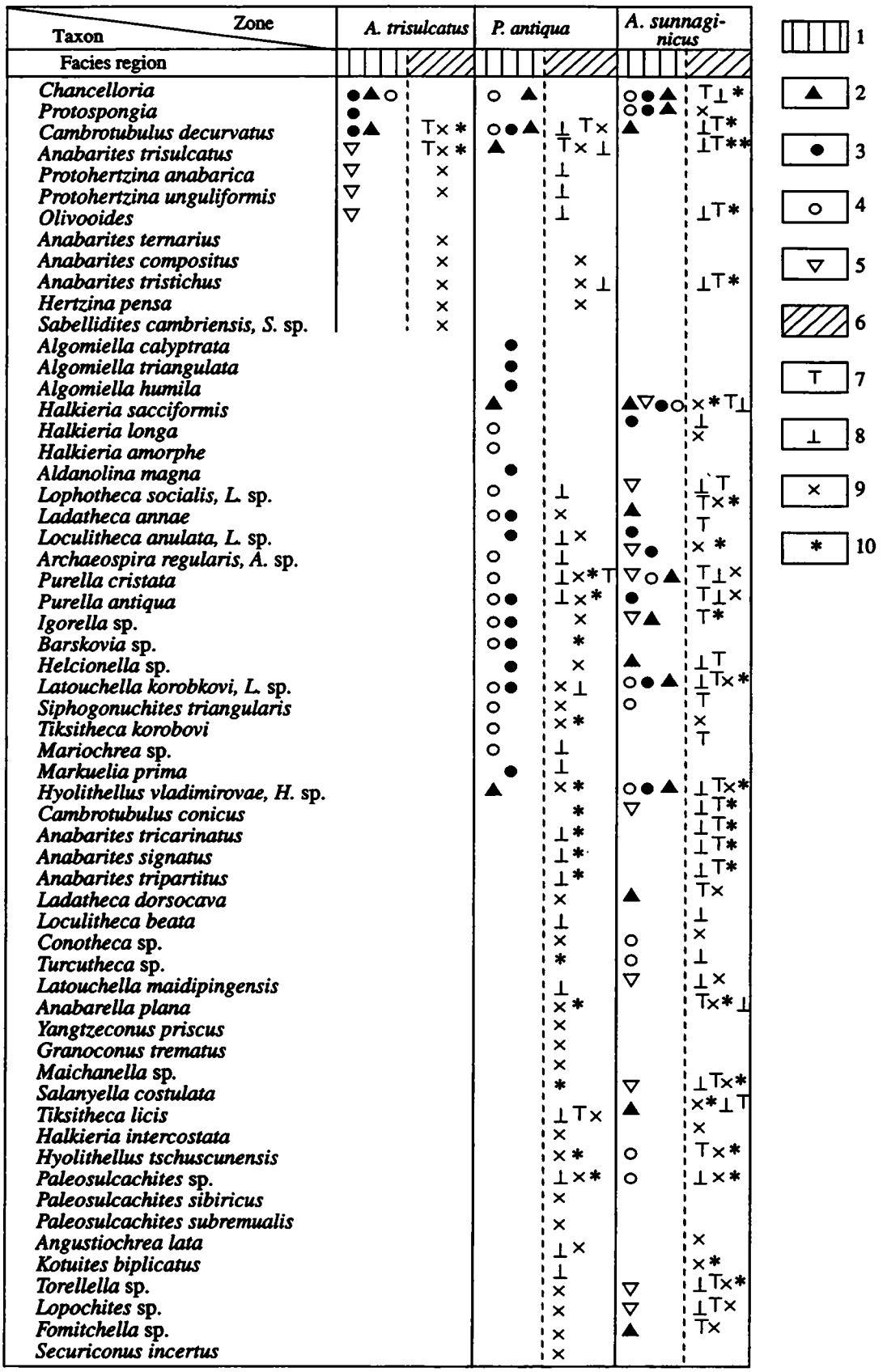
Taxon
Zone
Facies region
A. trisulcatus
P. antiqua
A. sunnagi-nicus
Chancelloria
Protospongia
Cambrotubulus decurvatus
Anabarites trisulcatus
Protohertzina anabarica
Protohertzina unguliformis
Olivooides
Anabarites ternarius
Anabarites compositus
Anabarites tristichus
Hertzina pensa
Sabellidites cambriensis, S. sp.
Algomiella calyptrata
Algomiella triangulata
Algomiella humila
Halkieria sacciformis
Halkieria longa
Halkieria amorphe
Aldanolina magna
Lophotheca socialis, L. sp.
Ladatheca annae
Loculitheca anulata, L. sp.
Archaeospira regularis, A. sp.
Purella cristata
Purella antiqua
Igorella sp.
Barskovia sp.
Helcionella sp.
Latouchella korobkovi, L. sp.
Siphogonuchites triangularis
Tiksitheca korobovi
Mariochrea sp.
Markuelia prima
Hyolithellus vladimirovae, H. sp.
Cambrotubulus conicus
Anabarites tricarinatus
Anabarites signatus
Anabarites tripartitus
Ladatheca dorsocava
Loculitheca beata
Conotheca sp.
Turcutheca sp.
Latouchella maidipingensis
Anabarella plana
Yangtzeconus priscus
Granoconus trematus
Maichanella sp.
Salanyella costulata
Tiksitheca licis
Halkieria intercostata
Hyolithellus tschuscunensis
Paleosulcachites sp.
Paleosulcachites sibiricus
Paleosulcachites subremualis
Angustiochrea lata
Kotuites biplicatus
Torellella sp.
Lopochites sp.
Fomitchella sp.
Securiconus incertus
1
2
3
4
5
6
7
8
9
10

Fig. 3. (Contd.)

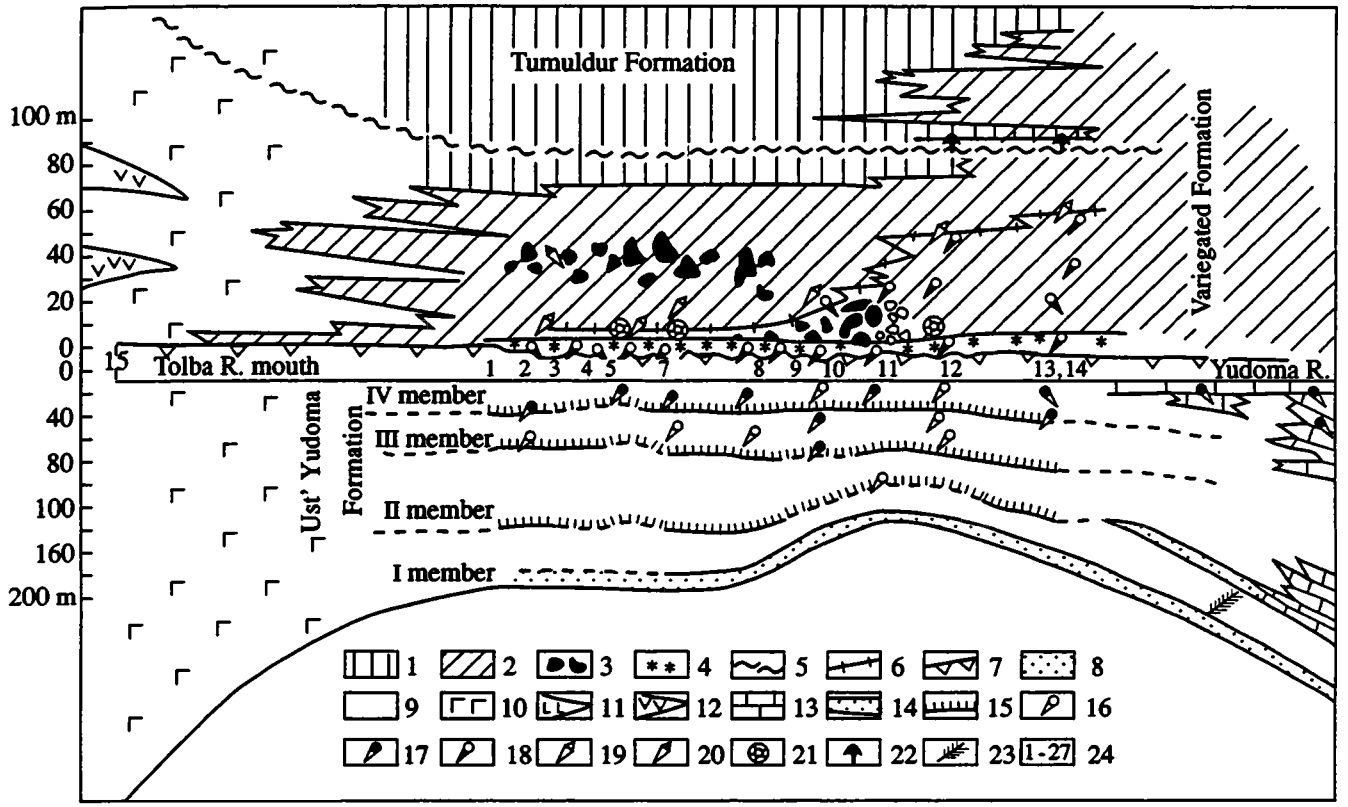

Fig. 4. Paleogeographic profile of the Vendian–Cambrian across the southeastern part of the Siberian platform.

1 – Gray carbonate rocks, 2 – essentially carbonate, carbonate-clay rocks, 3 – archaeocyathid-algal dolomites, 4 – abundant glauconite, 5 – lower boundary of the Atdabanian Stage, 6 – first appearance of the *regularis* Zone fossils, 7 – lower boundary of the Tommotian Stage, 8 – terrigenous-carbonate rocks of the Manykai and Kessyusa formations, 9 – gray dolomites, 10 – anhydrite dolomites, 11 – gypsum and anhydrite interbeds, 12 – salts, 13 – limestone, 14 – marker sandstone members, 15 – basal beds of the Ust' Yudoma Formation; 16 - 20 – hyolithids fossils: 16 – of the *trisulcatus* Zone, 17 – *antiqua* Zone, 18 – *sunnaginicus* Zone, 19 – *regularis* Zone, 20 – *lenaicus* Zone, 21 – Archaeocyatha, 22 – trilobites, 23 – Vendian–Ediacarian fauna, and 24 – Numbers of outcrops (name and location in Fig. 1).

of the Vendian deposits increased, and 2/3 of the dolomites of the Turkut Formation, analogous to those of the Staraya River Formation, are replaced by the Khatyspyt limestones (Fig. 5). The specific nature of the northern Vendian sections is the result of their vicinity to the Taimyr geosyncline, which promoted the enrichment of their upper parts with clastic material (the Manykai and Kessyusa formations). The lower parts of these formations are characterized by an assemblage of hyolithids fossils, typical of the *trisulcatus* Zone distinguished in the south of the platform. The upper parts of the Manykai Formation and the lower member of the Upper Kessyusa Subformation contain a representative assemblage of the *antiqua* Zone of the eastern type (Fig. 3).

The lower horizons of the Tommotian Stage within the Siberian platform are composed of two deposit varieties: gray dolomites in the west and variegated clayey carbonates in the east. A broad belt, in which grey evaporites are replaced by the Variegated Formation, extends in the south from the Tolba River as far as the village of Ugino at the Aldan River (Figs. 1, 4). Further to the east, between the village of Ugino and the Nemneker River, rocks of the Variegated Formation, though similar in appearance, were formed under different conditions. The Sunnagin member, composed of greenish-gray dolomitic sandstones with abundant glauconite, occur over the erosion surface at their base. In this member and the overlying brown one, which belong to the Variegated Formation, numerous erosion and ripple marks, cross-bedding, bird's eye structure, and numerous algae-archaeocyathid bioherms are found. In most cases bioherms do not exceed 1 - 5 m, however a small reef, discovered at the Nemnekei River, reaches 20 m in height. Its eastern part consists of typical frontal conglobreccia, marking the eastern border of the shallow water setting. In the eastern part of the Uchur plateau a further change in the depositional conditions of the Variegated Formation is observed. Signs of marginal shoal disappear. Erosion marks at its base appear insignificant, if at all present. The total thickness of the Variegated Formation considerably increases, because the overlying Tumuldur dolomites are replaced by rocks typical of the formation (Fig. 4). Bioherms completely disappear, and *Archaeocyatha* remnants are scarce. *Epiphyton* and *Renalcis* give way to more deepwater

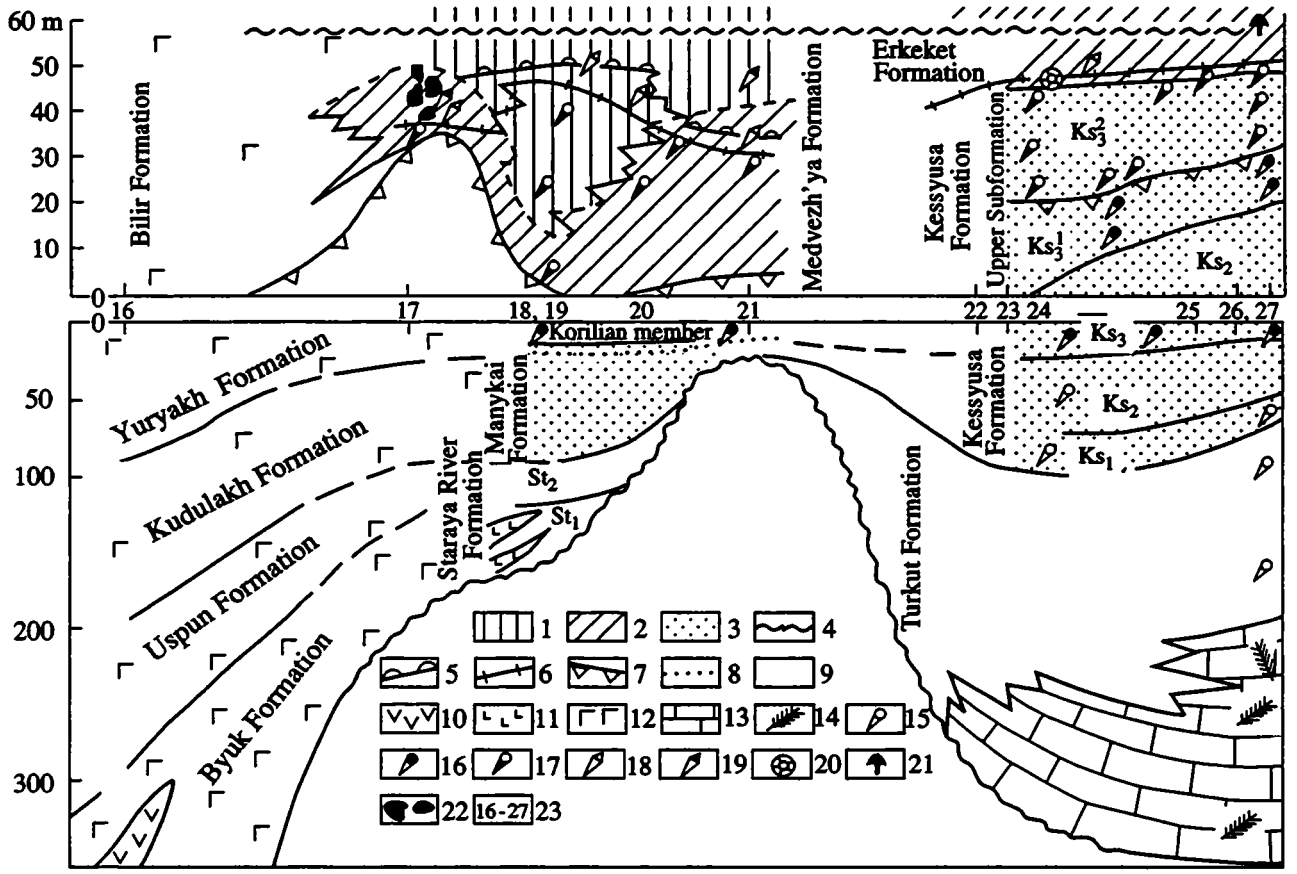

Fig. 5. Paleogeographic profile of the Vendian–Cambrian across the northern Siberian Platform. (See symbols in Fig. 4).

Proaulopora. Thus, though the subsidence rate was almost uniform throughout the basin, where the variegated deposits were formed during the Tommotian time, the area of the transitional sections was clearly elevated.

In the northern Siberian Platform, the sedimentation conditions peculiar to the transitional facies in the south are recorded only in the extreme southwest of the Anabar massif and in the Sukharikha River basin. In the first of the mentioned areas, variegated rocks of the Tommotian Stage appeared to have the same succession of Archaeocyatha assemblages (Shishkin *et al.* 1982), frequently forming bioherms (Fig. 5). The remaining area of the northern part of the platform belonged to the eastern facies zone of that time. So, at the beginning of the Tommotian epoch, a sedimentary uplift in the form of a narrow belt crossed the Siberian Platform from southeast to northwest. However, it was somewhat shifted relative to the Upper Vendian arch (Fig. 1).

In internal regions, the eastern facies zone certainly included the Yakutsk arch area, in which the deposits of the Ust' Yudoma and Variegated formations were dominated by limestones and limy dolomites. Further west, in the Berezovka and Vilyuchan facies zones, the thickness of the deposits sharply increased, and anhydrites and salt beds appeared here (*Resheniya* ..., 1989).

Thus, the sedimentation settings typical of the Lower Cambrian had already appeared in the Upper Vendian and greatly influenced the composition and areal distribution of hyolithids fauna (Khomentovskii and Karlova, 1992).

The eastern and transitional facies zones of the Siberian Platform at each of the three Siberian zonal levels (*trisulcatus*, *antiqua*, and *sunnaginicus* zones) were characterized by peculiar fossil groups, which can be divided into six large groups of biota (Fig. 3). The correlation of each couple of coeval biotas seems reliable if we summarize paleontological data on large areas. Due to certain factors, it is much more difficult to correlate individual sections of the facies zones under comparison. Sometimes, assemblages of hyolithids fossils appear in much younger layers without significant changes (Khomentovskii and Karlova, 1991, 1992). So, despite thorough searching, only scarce finds of the *trisulcatus* Zone forms were identified in Members III and IV of the Ust' Yudoma Formation along the Selinda River. Thus, in its entirety, Member IV of the Mt. Konus section is characterized by these fossils.

Particularly acute and vital is the current discussion on the correlation between lower parts of the Variegated Formation in the transitional and eastern facies zones. As we get further into the eastern facies zone, its pecu-

liar assemblage of typical fossils becomes gradually saturated upwards with increasingly more taxa, which are known from classical sections of the Aldan River as forms of the very base of the Tommotian Stage. Guide forms of younger zones of the Tommotian Stage appeared in this section even later. Along the Dzhanda River, for instance, the assemblage of the *sunnaginicus* Zone almost extends to the boundary of the Atdabanian Stage (Khomentovskii and Karlova, 1992).

There are sufficient reasons to conclude that in the northern Siberian Platform the reducted upper, principal part of the Tommotian Stage and disproportional thickness of beds of the *sunnaginicus* Zone result from the late appearance of the guide forms of the *regularis* Zone (Fig. 5). Disregarding the fact that most forms of the *sunnaginicus* Zone have a very wide stratigraphic range in transitional sections, some researchers locate the lower boundary of the Tommotian Stage, even in the eastern provinces, by the appearance of one of these forms, whereas faunal assemblages from more ancient layers are considered *a priori* to be pre-Tommotian (Val'kov, 1987; Missarzhevskii, 1989). The absence of such pre-Tommotian assemblages in the transitional facies zone is explained then by either an intensive erosion of the "pre-Variegated stage," or mutual transition between variegated deposits and gray Yudoma dolomites. A combined study of the continuous succession of well exposed sections within the Aldan–Uchur watershed showed that such suggestions are unfounded (Khomentovskii and Karlova, 1992).

Though the variegated deposits look similar, it was proven that along both the southern (Fig. 4) and northern (Fig. 5) transects of the Siberian Platform, the intense chemogenic sedimentation in the western evaporite basin was not favorable for Metazoa habitation. On the contrary, the well aerated and warmed shoal, separating the evaporite basin from the eastern open sea, should be the habitat of prosperous Siberian, mostly benthic, forms. Fossils are not so numerous in the eastern, deeper basin, partly uncompensated by sedimentation, though certain taxa, widespread in China and adjacent regions of Central Asia, are common among them. The trend of changes in biota composition from the transitional facies zone toward the eastern one resulted from a gradual invasion of shoal species into the transitional areas of the adjacent deeper basin. Evidently, they used the sea floor elevations and general shoaling of the eastern facies zone as it was gradually shifting toward the western uplift.

The migration rate of various taxa was different. It should be noted that large Upper Tommotian hyolithids with a minimal migration rate had the lowest phosphate content in shells (*Burithes distortus* (Sys.), *Tuojdachithes costulatus* Miss., *Crestjahitus compressus* Sys., *Notabilitus simplex* Sys. and others), and therefore usually are completely dissolved during chemical preparation.

In the elaboration of the stratigraphic scheme of Vendian–Cambrian deposits, we also encountered an opposite problem, the rare occurrence of some taxa below the level of their abundance. The notion of "mass occurrence" is unusual for the pre-Tommotian forms. Some time ago, it was believed that the first primitive fossils appear only 3 - 5 m below the base of the Variegated Formation, and even their reference to skeletal fauna was questionable. Only a few fossil-rich beds (coquinas) are so far known for this stratigraphic level. They usually occur as rare and small scattered lenses, which are difficult to discover. However, thorough investigations of well exposed sections in the transitional and eastern facies zones enabled us to identify the entire sequence of zonal assemblages for the Vendian–Cambrian interval. But even in this case the position of zone boundaries can be located using the combined paleontological and lithostratigraphic data. In the southern part of the platform, the lower boundaries of the *trisulcatus, antiqua* and *sunnaginicus* zones correspond to the base of Members III and IV of the Ust' Yudoma Formation and to the Sunnagin member of the Variegated Formation (Fig. 4). Here, we had to consider the first appearance of form to be the scarce finds of rare fossils discovered in well-studied regions below the levels of their usual occurrence, i.e., below the zone boundaries. Thus, in the Nemnekei River section, *Anabarites trisulcatus* Miss., *A. valcovi* Fed., *Protohertzina anabarica* Miss., and *P. unguliformis* Miss., typical of the *trisulcatus* Zone, were found in the lowermost parts of member II of the Ust' Yudoma Formation, but not observed in member III (Khomentovskii and Karlova, 1991). The forms of this zone, as *Anabarites trisulcatus* Miss. and *Cambrotubulus decurvatus* Miss., were also recovered from the interval 10 - 30 m below the top of the Turkut Formation, i.e., formally below the Nemakit–Daldyn Horizon. *Oelandiella* sp., *Archaeospira* sp., and *Lophotheca socialis* Val., known only in the *antiqua* Zone of the Mt. Konus locality, were identified in the lower parts of member III of the Ust' Yudoma Formation (Khomentovskii *et al.*, 1990). At the Olenek uplift we encountered *Tiksitheca* sp. and chiolite fragments several times near the Kessyusa Formation base, though everywhere the entire range of its lower and middle subformations is characterized by forms typical of the *trisulcatus* Zone. Fossils of the *antiqua* Zone, also comprising the above-mentioned taxa, are abundant only in the lower member of the upper subformation of the Kessyusa Formation.

It is difficult to explain the mentioned anomalies in fossil distribution through the section horizons by a mere change in the composition of host rocks. It seems that peculiarities of the Vendian–Cambrian biota are less dependent on biological type of the taxa in its composition, than on their ability to be preserved in the sediment. Apparently, this is related to the instability of the Metazoa skeleton, which, at that time, was undergoing the first stage of its development. Such a supposition agrees well with the predominance of fine fossils, congruent in size with sandy clastic material, and rapidly buried under sediments. At the same time, larger fossils had to be crushed and destroyed. Their existence at that time was confirmed by finds of the peculiar mollusks

Algomiella in the lower part of Member IV of the Ust' Yudoma Formation, 1.5 cm in size (Val'kov and Karlova, 1984). The absence of such forms elsewhere, despite a long search, might be explained by their instability in the burying process. In addition, in this stratigraphic horizon we often observed fragments of large forms.

There is every reason to suggest that at the early stages of the outer skeleton development, the ability of a shell to be preserved in a sediment was to a large extent dependent upon the chemical composition of the water or sediment, and, in particular, on the P_2O_5 content in the shells. First of all this is confirmed by the fact that all ancient shells in Siberia, Mongolia, and China are phosphatic; a fact open to various interpretations. It is known that the maxima of phosphate accumulation and the P_2O_5 content in sea water were in the Upper Vendian and the Lower Cambrian (Yanshin and Zharkov, 1986). The oldest assemblages of phosphatic small-shelly fossils, which correspond to the *trisulcatus* Zone in China (Luo Huilin *et al.*, 1984), Mongolia (Gibsher and Khomentovskii, 1990), and in several other regions, appear near the level of first phosphorite layers. In Siberia, the oldest Vendian–Cambrian phosphorite deposits are concentrated in framing fold belts and, most likely, related in origin to the upwelling. However, the above-discussed peculiarities of the Siberian basin hydrodynamics directly affected P_2O_5 redistribution in the entire area of the Siberian platform. A "huge distillery," i.e., the evaporite basin in the southwest of the platform, had a decisive role in this process. In order to be active, it had to be supplied continuously with large amounts of water from outside, including basins with high P_2O_5 content. Numerous chemical analyses of the Vendian–Cambrian rocks from the Uchur plateau, where the above-considered profile is located (Fig. 4), indicate that their phosphorus content amounts up to thousands ppm. The initial P_2O_5 content in the sea water of various facies zones of the Siberian platform could be nearly equal, but abundant biomass in the well aerated and warmed shoal of the transitional zone would oversaturate its waters with phosphorus. On the contrary, a high intensity of sedimentation in the evaporite basin unfavorable for life caused a considerable decrease of the phosphate content in sediments. In this respect, the deeper water basin of the eastern facies zone was in an intermediate state. Accordingly, the oldest and richest localities of hyolithids fossils occur in the central and eastern parts of the transitional facies zone. In addition to very abundant local, mostly benthic forms, representatives of deeper cosmopolitan taxa penetrated here from the eastern facies zone.

Local changes in the phosphate content could be responsible for the above-mentioned penetration of ancient assemblages upwards in the section and for the rare appearance of some younger forms in lower stratigraphic horizons, as biomineralization of different taxa shells requires different concentrations of P_2O_5 in the water. A low phosphate content in the deeper eastern basin caused a stagnation of the *sunnaginicus* Zone assemblage, because of slow westward distribution of phosphatic remains of hyolithids taxa, which rapidly appeared in the transitional facies zone with a wide diversity of forms. The particular slowness in the distribution of hiolithids with large low-phosphate shells, the dissolution of which increased with deepening of the basin, is also quite understandable. A substantial increase in P_2O_5 content over vast territories of modern Asia during the Vendian–Cambrian time resulted in a deposition of the oldest assemblages of hyolithids fossils concentrated here. In Newfoundland and several other regions, where the considered event was not so distinct, skeletal fauna appeared much later, at the end of the Tommotian–the beginning of the Atdabanian time.

The termination of the epoch of "phosphate" seas, which started in Siberia and China in the mid-Tommotian time, was characterized by a sharp decrease in the abundance and diversity of phosphatic fossils. Against this background, the insignificant amount of large low-phosphate hyolithids of the Middle-Upper Tommotian played a more important role in the poor fossil assemblages.

The foregoing discussion leads us to the conclusion that in the Vendian–Cambrian time, when biomineralization of the outer essentially organic cover of Metazoa had just begun to transform gradually into a real shell, even insignificant ecological changes greatly affected the composition and geographic distribution of different fossil assemblages. At that time these changes could either strongly emphasize evolutionary transformations, or, on the contrary, conceal them.

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REFERENCES

Gibsher, A.S. and Khomentovskii, V.V., The Section of the Vendian–Lower Cambrian Tsaganolom and Bayangol Formations in the Dzabkhan Zone of Mongolia, *Dokembrii i Rannii Paleozoi Sibiri, Voprosy Regional'noi Stratigrafii* (The Precambrian and Early Paleozoic in Siberia. Problems of Regional Stratigraphy), Novosibirsk: Inst. of Geology and Geophysics, Siberian Division, Akad. Nauk SSSR, 1990, pp. 79 - 91.

Hofmann, H.J., Narbonne, G.M., and Aitkin, J.D., Ediacarian Remains from Intertillite Beds in Northwestern Canada, *Geology*, 1990, vol. 18, pp. 1199 - 1202.

Khomentovskii, V.V., Baikalian, the Essential Stage of the Geological Evolution of Siberia, *Geologiya i Geokhronologiya Dokembriya Sibirskoi Platformy i Ee Obramleniya* (Precambrian Geology and Geochronology of the Siberian Platform and its Framing Structures), Moscow: Nauka, 1990, pp. 222 - 237.

Khomentovskii, V.V., Vendian of the Siberian Platform, *Vendian System*, vol. 2, Berlin: Springer, 1990, pp. 102 - 183.

Khomentovskii, V.V. and Karlova, G.A., Biostratigraphy of the Vendian–Cambrian Beds and the Lower Cambrian Boundary in Siberia, *Geol. Mag.*, 1993, vol. 30, no. 1, pp. 29 - 45.

Khomentovskii, V.V. and Karlova, G.A., The Lower Boundary of the Cambrian and Principles of Its Substantiation in Siberia, *Geol. Geofiz.*, 1992, no. 11, pp. 3 - 26.

Khomentovskii, V.V. and Karlova, G.A., New Data on Correlation between Eastern and Transitional Facies Zones of the Vendian–Cambrian Deposits in Southern Yakutia, *Pozdnii Dokembrii i Rannii Paleozoi Sibiri. Sibirskaya Platforma i Ee Obramlenie* (Late Precambrian and Early Paleozoic in Siberia. The Siberian Platform and Its Framing Structure), Novosibirsk: Inst. of Geology and Geophysics, Siberian Division, Akad. Nauk SSSR, 1991, pp. 3 - 40.

Khomentovskii, V.V., Val'kov, A.K., and Karlova, G.A., New Data on Biostratigraphy of the Transitional Vendian–Cambrian Beds in the Basin of the Aldan River Middle Stream, *Pozdnii Dokembrii i Rannii Paleozoi Sibiri. Voprosy Regional'noi Stratigrafii* (Late Precambrian and Early Paleozoic in Siberia. Problems of Regional Stratigraphy), Novosibirsk: Inst. of Geology and Geophysics, Siberian Division, Akad. Nauk SSSR, 1990, pp. 3 - 58.

Luo Huilin, Jiang Zhiwen, Wu Xiche, *et al.*, Sinian–Cambrian Boundary Stratotype Section at Meichucun, Jinning, Yunnan, China. Yunnan: People's Publishing House,1984.

Missarzhevskii, V.V., *Drevneishie Skeletnye Okamenelosti i Stratigrafiya Pogranichnykh Tolshch Dokembriya i Kembriya* (Ancient Skeletal Fossils and Stratigraphy of Precambrian–Cambrian Boundary Beds), Moscow: Nauka, 1989.

Resheniya Chetvertogo Mezhvedomstvennogo Regional'nogo Stratigraficheskogo Soveshchaniya po Utochneniyu i Dopolneniyu Stratigraficheskikh Skhem Venda i Kembriya Vnutrennikh Raionov Sibirskoi Platformy (Resolutions of the Fourth Interdepartmental Regional Stratigraphic Conf. on Precising and Supplementing Vendian and Cambrian Schemes for Inner Areas of Siberian Platform), Novosibirsk: Inst. of Geology and Geophysics, Siberian Division, Akad. Nauk SSSR, 1989.

Resheniya Vsesoyuznogo Stratigraficheskogo Soveshchaniya po Dokembriyu, Paleozoyu, i Chetvertichnoi Sisteme Srednei Sibiri. Chast' I. Verkhnii Proterozoi i Nizhnii Paleozoi (Resolutions of the All-Union Stratigraphic Conf. on the Precambrian, Paleozoic, and Quaternary Systems in Central Siberia. Part I. Upper Proterozoic and Lower Paleozoic), Novosibirsk: Inst. of Geology and Geophysics, Siberian Division, Akad. Nauk SSSR, 1983.

Shishkin, B.B., Fedorov, A.B., and Sundukov, V.M., The Kotui Archaeocyatha Horizon in the Southwestern Anabar Region, *Novye Dannye po Stratigrafii Pozdnego Dokembriya Sibiri* (New Data on the Late Precambrian Stratigraphy in Siberia), Novosibirsk: Inst. of Geology and Geophysics, Siberian Division, Akad. Nauk SSSR, 1982, pp. 20 - 30.

Val'kov, A.K., *Biostratigrafiya Nizhnego Kembriya Vostoka Sibirskoi Platformy. Yudomo-Olenekskii Region* (Lower Cambrian Biostratigraphy in the Eastern Part of the Siberian Platform. The Yudoma–Olenek Region), Moscow: Nauka, 1987.

Val'kov, A.K. and Karlova, G.A., Fauna from Vendian–Cambrian Boundary Beds of the Gonam River Lower Stream, *Stratigrafiya Pozdnego Dokembriya i Rannego Paleozoya. Srednyaya Sibir'* (Late Precambrian and Early Paleozoic Stratigraphy. Central Siberia), Novosibirsk: Inst. of Geology and Geophysics, Siberian Division, Akad. Nauk SSSR, 1987, pp. 12 - 41.

Yanshin, A.L. and Zharkov, M.A., *Fosfor i Kalii v Prirode* (Phosphorus and Potassium in Nature), Novosibirsk: Nauka, 1986.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 216 - 221. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 18 - 23.
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Evolution of the biosphere

The Paleozoic Stages of Reef Formation

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Abstract – The Paleozoic reef ecosystem evolved through three stages. At the first stage (the Early Cambrian), algae and archaeocyathids were the principal organisms building biogenic buildups, still frameless. At the second stage (from the Middle Ordovician to the Devonian), algae, stromatoporoids, bryozoans, and corals began to form the framework structure; the Devonian reefs are analogous to the recent ones. At the third stage (the Late Paleozoic), reefs were built by algae and bryozoans.

The evolution and distribution of carbonate biogenic buildups in the Earth's history were uneven. Periods of high diversification of various biogenic buildups alternated with periods of sporadical occurrences, when no new types appeared. Previously, we discussed some aspects of this problem, including the terminology (Bol'shakova *et al.*, 1993, 1994). The present study concerns a detailed analysis of trends in Paleozoic reef formation.

The reef formation was mainly affected by the following factors:

(1) Tectonic lateral movements. A convergence of continental lithosphere plates reduces shelf areas, thus, destroying potential zones favorable to reef formation, whereas fragmentation and divergence of continents result in an increase of coastal line length and shallow-water area. Related to lateral movements, the location of the continental massives and the shallow-water areas favorable to reef formation, i.e., their location in hospitable or inhospitable latitudes, is of greater importance. Tectonic movements and other endogenic processes cause the appearance of positive landforms, such as block and arch uprises of the oceanic floor, shallow-water areas, "hot spots," volcanic islands, and, consequently, atolls at the basin floor.

(2) Tectonic vertical movements, sedimentation, and fluctuations in the system of the continental ices (pluvial periods) – World Ocean result in eustatic changes in the sea level, alternation of transgressions and regressions and of thalassocratic and geocratic epochs, which, respectively, more or less favor reef development.

(3) Climatic changes and related oceanic circulation can be caused both by some cosmic factors and by tectonic movements (the latitudinal position, relative height and continuity of continents, and others). For example, two different regimes of reef development occurred in the Early Cenozoic, when the transequatorial water exchange was in progress, and in the Quaternary, when the reef formation zones were separated by continents.

Besides the abiotic factors, there are some biotic ones that also play a significant role. So, before some Paleozoic groups of Metazoa appeared, the sole type of biogenic buildups (stromatolites) had been developing for nearly 2 Ga. During the Paleozoic, the competitive organisms began to supercede the blue-green algae (Cyanobacteriae) in the main areas of carbonate sedimentation. Modern stromatolites are developed only in semi-isolated water areas of high salinity.

An alternation of periods of activity and fading of the reef formation proceeded as a result of the complicated relationships between these and, probably, other factors; the number of combinations are too great to indicate only cyclicity and recurrence. Therefore, it is difficult to elaborate a simple scheme in which periods of reef development would coincide, for example, with the large Phanerozoic cycles of cosmic origin (Fisher, 1986).

The time of changes in the reef-building biotas and corresponding ecological crises was marked by well

expressed events, in contrast to the longer and stable periods, when new reef ecosystems were formed and distributed.

The question of whether the pre-Paleozoic stromatolitic buildups created by Cyanobacteriae can be referred to as reefs remains open. Many of these buildups are similar in their paleogeographical position to the younger reef systems. According to the paleoreconstructions, some of them resembled the fringing reefs, which lacked reef flats but had an advanced buttress in the outer slope, i.e., they existed under conditions of active wave dynamics. A stromatolite growth led to the formation of structures elongated in the direction of wave action, relief amplitude reached about 3 m. Cross-bedded and coarse-grained sands and coarse clastics accumulated in the groves between these structures (Hofman, 1974). In the Phanerozoic, skeletal organisms as well as algae played a major role; their evolution determined to a great degree the developmental changes in the reef formation.

There are three distinct stages in the development and distribution of the biogenic buildups in the Paleozoic: the Early Paleozoic stage (the peak occurs from the Early Cambrian to the beginning of the Middle Cambrian), the Middle Paleozoic stage (the peak occurs from the Silurian to the Frasnian), and the Late Paleozoic stage, whose peak is in the Permian. We will dwell on peculiarities of each of them.

All biogenic buildups from the Early to the beginning of the Middle Cambrian were formed by the blue-green algae and archaeocyathids, which did not produce frames. These buildups are widespread in the Siberian platform and surrounding fold belts (the Altai–Sayan, Lake Baikal, and Amur–Sea of Okhotsk regions) as well as in the Urals. The frameless buildups of this type can be traced up to the recent times, although the taxonomical composition of the building organisms responsible for the sedimentation of predominantly pelitomorphic material and the accumulation of their skeletal calcium carbonate changed many times during the Earth's history. In general, the platform areas show widespread submerged buildups. Reef formation ceased in the Late Cambrian–Early Ordovician.

The Middle Paleozoic stage lasted from the Middle Ordovician to the Famennian. At this time, one of the most compound ecosystems – a coral reef ecosystem – originated owing to the considerable extension of the shelf zone and the wide distribution of warm, shallow, epicontinental seas. Its principal features can be traced up to recent times. The stage is generally characterized by thick long-existing reefs spread widely in the folded areas (the Urals, southern West Siberia, Kazakhstan, Tien Shan, Verkhnyaya Yana–Kolyma region) and the ancient platforms.

This time is marked by a variety of reef types. First, the extensive asymmetrical reef systems prograding frequently toward the open deep sea. They include the "Hercynian limestones" of the Urals and Novaya Zemlya (the Ludlow–Eifelian), the reefs of the Pechora syneclise (the Frasnian), the reef systems of the western marginal zone of the Caspian syneclise (the Middle Devonian–Frasnian), and others. These reef systems occurred both in the platforms and the geosynclinal zones, always closely related to sea floor warping. They developed near the boundary between shallow and deep sea areas. Second, solitary buildups that occur in the vast, shallow, epicontinental basins. For example, such reefs are described from the Middle Devonian and Frasnian of the Saratov area. At last, the solitary reefs or reef chains occurring predominantly in the deep-water zones of the geosynclinal areas. They developed on some tectonic and volcanic elevations (the Caradocian of the northern Kazakhstan, the Devonian of the Tien Shan). Apparently, these reefs were typical of this period in the Earth's history. So, the extensive reef systems (the Hay River and others) and contemporaneous solitary reefs, including atoll-like ones, are known from the Givetian–Frasnian of the West Canadian basin. The Devonian reef systems are described from the Canning Basin, Australia. Intensive reef formation on volcanic bases occurred in Harz, Germany during the Givetian–Frasnian.

Two reef formation substages differing in place and time can be recognized in the platform areas. At the first substage (the Middle-Late Ordovician to the Ludlow), the reef formation concentrated in the western region of the East European platform; small buildups in the form of bioherms are known from the Siberian platform. The second substage was fixed in the eastern region of the East European platform. The reefs intensively developed in the Pechora and Caspian syneclises and in some depressions of the Volga–Ural anteclise from the Middle Devonian (the Givetian–Eifelian) to the end of the Frasnian.

The oldest framework buildups appeared in the Middle Ordovician. They were characterized by compound ecosystems, which were highly effective in producing calcium carbonate. At that moment the principal frame-producing organisms – stromatoporoids, bryozoans, and corals (algae are known to have existed since the Cambrian) – appeared. Most of these organisms were colonial. The colonial life, stimulating a high rate of skeletal organism formation, led to the appearance of reef ecosystems analogous to recent ones.

A compound system of ecological niches and numerous feedbacks made the ecosystem more stable. The framework formation changed environmental parameters locally, such as illumination intensity, hydrodynamics, ground inclination, and distribution of substrates. An intense evolutionary radiation of principal reef-dwelling organisms, including echinoderms, and, thus, a sharp change in composition and properties of ground in the shallow shelf and epicontinental seas occurred at that moment.

It is not clear yet what environmental changes caused these phenomena. However, this is considered one of the most important problems concerning biosphere evolution.

Perhaps, simultaneously many representatives of benthos became capable of symbiosis with zooxanthellas. This led to the appearance of highly effective ecosystems producing calcium carbonate. This suggestion is supported by the fact that the period of diversification of blue-green algae and the wide expansion of green algae coincides with the beginning of the Middle Ordovician. Owing to their symbiosis with algae, the reef-forming corals were able to occupy vast oligotrophic areas of the open ocean.

This period is also marked by the appearance of cystoid and laminar stromatoporoids, all main groups of tabulatomorphs (heliolitids are likely to appear later), and the solitary and polyparia-forming rugoses. The first representatives of bryozoans, Ceramoporina and Esthonioporina, recorded from the Arenigian did not contribute to the biogenic formation. The true bryozoan bioherms appeared in the Middle Ordovician. Later, Phylloporinina, Ptylodictyina, and Goldfussitrypina joined the bioherm builders.

Echinoderms were the principal Paleozoic reef-dwelling organisms, often filling the cavities in the reef frameworks. Representatives of different groups of the echinoderms commonly formed a belt bordering a bioherm or a reef and, thus, contributed to the reef formation. Some echinoderms, e.g., the Middle Ordovician *Cyathocystis* (Edrioasteroidea), produced the frameworks.

During the Middle-Late Ordovician transgression, the increased reef formation occupied new, warm, shallow areas of the enlarged shelves. The end of the Ordovician was marked by a regression and a cooling; many hospitable epicontinental tropical basins became land. This resulted in the taxonomical changes in many benthic groups, primarily cnidarians, at the Ordovician–Silurian boundary.

After the rearrangement of the basins at the beginning of the Llandoverian, reef formation resumed locally. Such reef inhabitants as corals were ordinary members of communities and seldom dominated them. The increased Middle Llandoverian transgression eliminated the moderately deep-water areas favorable for corals, which existed at the end of the Ordovician. In addition to the dominating algae, stromatoporoids, and bryozoans, the Silurian reef-forming organisms included the corals: the tabulates (Favositidae, Syringoporidae, Auloporidae, and Halysitidae), Heliolitoidea, and to a lesser degree rugoses (Streptelasmatidae and Arachnophyllidae).

The first framework buildups were not as distinctly zoned as the recent reefs and resembled domes or deep-water banks of simple structure, whereas the Silurian buildups were more diverse. Manten (1971) distinguished three types of the buildups, the Upper Visby, Hoburgen, and Holmhällar, from Gothland Island on the basis of lithological composition, size, and reef-forming organisms (mainly, the corals and stromatoporoids). Buildups of these types are also recorded from other regions, e.g., Welles, the Baltic region, Siberian platform, and the Great Lakes area in North America. Small marlaceous cone-shaped mounds with abundant corals referred to as the Upper Visby type are most widespread.

The oldest reefs similar in structure to the recent ones are known from the Devonian. During the maximum transgression from the Middle Devonian to the Frasnian, the contribution of the corals to the framework formation was as great as in the recent times. It became minor in the Silurian and negligible in the Late Paleozoic.

A brief Late Silurian–Early Devonian regression, which, it seems, was not catastrophic was followed by a transgression. The long period from the Lochkovian to the Frasnian was characterized by increasing reef formation activity, which was most intense in the Emsian and the Eifelian, when the warm shallow seas occupied most of the modern land and environments were very favorable for the reef-dwelling organisms.

Calcareous algae played a minor role in the Devonian reef formation. The blue-green algae predominated, while the red (*Solenopora* and *Parachaetetes*) algae were less abundant. A brief outburst of the Siphonophyceae was recorded for the Middle Devonian. All three Siphonophyceae orders were highly diversified in the Middle-Late Devonian.

The Devonian is characterized by a variety of stromatoporoid life forms, which had a distinct zonal distribution on the reefs. The reef-forming bryozoans were dominated by Amplexoporina, Fistuliporina, and Fenestellina.

The large reef buildups known from the Middle Devonian and the Frasnian of Russia were a part of the reef belt stretching throughout Eurasia. They are characterized both by a wide geographical distribution and a variety of frame-producing organisms.

The Frasnian–Famennian boundary crisis continued in the Tournaisian and was marked by the mass extinction of stromatoporoids, corals, and other marine invertebrates. Framework building was replaced by "mud mound" formation. The Famennian–Tournaisian buildups are widely distributed in Belorussia, the Timan–Pechora province, Ural–Volga region, Kazakhstan, Tien Shan, and to a lesser degree in the Urals and the Verkhnyaya Yana–Kolyma region. A variety of their types from lamellar biostromes to thick structures of relief morphology are observed there. An impoverished composition of frame-producing organisms dominated absolutely by the algal communities is peculiar to these buildups. The onset of this framework formation crisis correlates well with the known Kellwasser Event at the Frasnian–Famennian boundary. Geochemical anomalies in sulfur and carbon isotope composition and anomalous high concentrations of some elements (Zn, Cu, V, Co, Ni, Sb, and Fe) characteristic of the anaerobic environments of the World Ocean (Joachimski and Buggisch, 1993) are recorded in many regions of Central Europe, Australia, and Canada, i.e., almost globally. The anaerobic environments could have caused the extinction of highly organized marine skel-

etal benthic fauna and the flourishing of Cyanobacteriae and other algae tolerant of them.

A new stage of the intense Paleozoic reef formation occurred from the Visean to the Permian. The active tectonic movements and rapid tectonic subsidence, which began in the second half of the Carboniferous, led to the reappearance of the communities of the framework-forming skeletal fauna, which determined reef formation during the Late Paleozoic. These reefs are widespread in the eastern region of the East European platform and the Cis-Ural depression as well as in the Pacific folded belt (the Verkhnyaya Yana–Kolyma, Chukotsk, and Sikhote-Alin' folded systems). In the first region, this stage can be subdivided into two substages: the Visean–Early Bashkirian and Middle Moscovian–Early Permian. The reef formation peak occurred in the Early Permian. In the Pacific region, the active reef formation continued in the Late Permian as well.

This stage is characterized by different types of reefs. As before, predominantly the asymmetrical reef systems fringing the large uncompensated depressions – the Caspian syneclise and the Cis-Ural foredeep. The solitary reefs and their associations occurred in the deep-water basins. These reefs are represented by domelike and tablelike buildups (the Cis-Ural foredeep and the Caspian syneclise). The solitary reefs were formed locally on the bases of older reef systems. For example, the Sakmarian–Artinskian domelike reefs occur on the Asselian asymmetrical systems in the Ural region. Some domelike buildups originated from the atoll-like ones, e.g., the Permian part of the Karachiganak reef in the Caspian region. The solitary reefs are also known from the shallow basins. Morphological reef types from the Russian folded areas have not been adequately studied.

A specific peculiarity of this stage, the corals as the framework-forming organisms were substituted by the algae and bryozoans, although the former still existed on reefs. This phenomenon can be explained by the fact that the Early Carboniferous corals survived only in the deep areas of marine basins inherited from the Famennian (Sando, 1980; Poty, 1980; and others). After the crisis, the taxonomic diversity of the tabulates and rugoses was sharply reduced. Before the corals were able to spread over the shallow shelf, the reef systems had been already formed, and the corals did not appear to compete with the algae, chaetetids, bryozoans, and sphinctozoans inhabiting the systems. But after the Late Paleozoic crisis, which was more catastrophic than the Famennian one, favorable environments were restored and the corals became dominants on the Middle Triassic reefs. The unfavorable cold Late Paleozoic environments have been caused by a climatic cooling.

The Late Paleozoic is characterized by flourishing green and red algae and a subordinate role of the bluegreen algae. The Carboniferous bryozoans, which generally entraped and accumulated sediments, are represented by the Rhabdomesina, Fenestellina, and Amplexoporina suborders, the Permian bryozoans, by Fenestellina, Fistuliporina, and Timanodictyina. The Paleozoic bryozoans became extinct by the end of the Permian. In the Triassic, the bryozoans were completely renewed taxonomically but retained their constructive role in the reef formation. The colonial shape was not significantly modified.

The next crisis in the reef formation began in the second half of the Permian. However, as in the Famennian-Tournaisian, the reef-building was continued mainly by algae and to a lesser extent by bryozoans. The biostromes, bioherms, and reefs of the Zechstein in Europe, which extend from the Baltic region via Poland, Germany, the Netherlands and Denmark to the eastern coast of Great Britain, and the reefs of the Permian basin in the USA are the most widely known.

In general, the described events correspond to the global cyclic occurrence of reef formation and evolutionary stages of the reef-producing communities. Some suggestions were made to explain this periodicity. So, Copper (1989) argued that the periodic sharp increases in the mass carbonate accumulation during the Earth's history were caused by global warmings, although this suggestion is not in accordance with the temperature data for the last, the Eocene–Holocene, period of the intensive reef formation. The hypothesis that the periodic appearance and disappearance of the ecological shelf niches favorable for the ecosystem development are related with the continental drift seems more valid; a point supported by the fact that climatic conditions are determined to a large degree by the World Ocean circulation, i.e., by continental plate drift.

The hypothesis that the Paleozoic reef ecosystem degraded due to the global coolings (Stanley, 1988; and others) is supported by the fact that the reef formation crises coincided with glaciations and a general decrease in the carbonate sedimentation in these epochs. A disappearance of taxa peculiar to the tropical localities is also noted for this time, while the surviving groups of organisms are cosmopolitans. Sometimes the Tremadocian to Middle Caradocian and Tournaisian to the middle of Late Carboniferous periods are named "a time of repressed reef formation" (Copper, 1989), when the biogenic buildups were small and constructed mainly by the algae. Diverse corals and other Metazoa, which spread widely over the basins, played a minor role in the reef formation.

The tectonic events, i.e., the character of the movements and the position of the continental plates, seem a more actual cause. The continental convergence near the Devonian–Carboniferous and Permian–Triassic boundaries resulted in the destruction of the shelf seas and, hence, in changes in the directions of the main sea currents, climatic deterioration, and even glaciations. In other words, both the reef ecosystem crises and the climatic changes were effects of the same cause, and none of these phenomena preceded the other. Taxonomically the Devonian and Middle Mesozoic reef ecosystems are analogous to each other but sufficiently differ from the Late Paleozoic ones being only partly similar to

them. This can be explained by the warm tropical climatic conditions during the former periods, while the Late Paleozoic climate was much cooler in most of the Earth's regions.

CONCLUSION

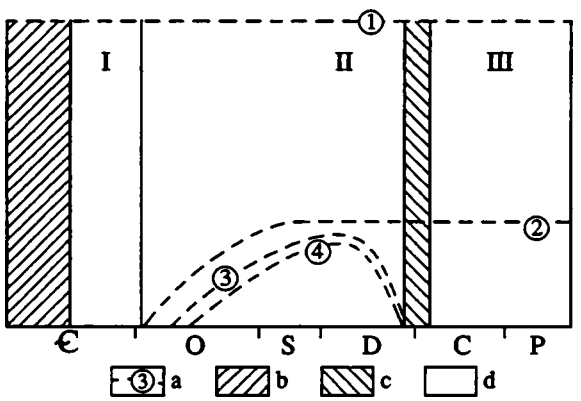
The Paleozoic reef ecosystem evolved through three stages. At the first stage (the Early Cambrian), algae and archaeocyathids were the principal organisms building biogenic buildups, still frameless. At the second stage (from the Middle Ordovician to the Devonian), algae, stromatoporoids, bryozoans, and corals began to form framework buildups; the Devonian reefs are analogous to the recent ones. At the third stage (the Late Paleozoic), the reefs were built by algae and bryozoans (the figure).

The intensive reef formation occurring in the Early Cambrian, Middle-Late Devonian, and Permian corresponds to the periods of active tectonic movements (Ronov, 1980). The long Middle Cambrian–Early Ordovician pause corresponds to the more stable position of the continental blocks. In the Ordovician, the active tectonic movements resulted in a differentiated subaquaeous topography and the first appearance of the uncompensated depressions (*Tektonika Evrazii*, 1966).

The colonial frame-producing organisms probably appeared in response to the topography differentiation and the high rate of the tectonic subsidence, because those organisms capable of significant carbonate accumulation and the formation of biogenic buildups could have compensated for the intense tectonic subsidence (Kuznetsov, 1983, 1986). The disposition of the lithospheric plates on the Earth's surface affected both the global climatic conditions and the location of the basins, which favor reef development with respect to geomorphologic and tectonic environments in the corresponding climatic zone. So, in contrast to the Late Cambrian–Early Ordovician period, the second half of the Ordovician shows a convergence of continents and an appearance of large continental masses in the southern circumpolar area. In the Late Permian, an analogous process resulted in the joining of continental plates and the appearance of the submeridional supercontinent, a major part of which was located in the southern hemisphere, including the circumpolar area.

Several reef formation phases can be recognized against the background of the large stages. The boundaries between the phases were not marked by radical catastrophic changes in the ecosystems. This is most clearly demonstrated by the Ordovician–Devonian period. In these periods, activity or fading of the reef formation was caused by expansion or reduction of the water areas, i.e., transgressions or regressions.

In addition, the reef building processes were dissymmetrical and diachronous, because of the dissymmetrical and diachronous occurrences of the tectonic events in different regions. This was best expressed in the Late Paleozoic. In the Pacific segment (the Koryak–Kamchatka and Sikhote–Alin' folded systems, the Permian basin in the USA), the Late Permian was characterized by intensive reef formation; the frame-producing organisms were dominants among the reef builders. In contrast, the Late Permian reef formation was obviously repressed in the Atlantic segment; the principal reef builders were the blue-green algae. The Middle Paleozoic reef forming processes were not synchronous in the western and eastern regions of the East European platform. Changes in types, height, and thickness of the reefs are also recorded for that time.



The Paleozoic stages of reef formation.

I, II, III – Stages of reef formation; a – curves representing the relative role of different organisms in the reef formation: 1 – algae and cyanobacteria, 2 – bryozoans, 3 – stromatoporoids, and 4 – cnidarians; b – an epoch of buildups formed by cyanobacteria and archaeocyathids; c – an epoch of buildups formed by algae and cyanobacteria; d – an epoch of framework buildups, including reefs.

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REFERENCES

Bol'shakova, L.N., Gekker, M.R., Ivanovskii, A.B., Kosmynin, V.N., Sokolov, B.S., and Ulitina L.M., The Basic Trends in the Evolution of Coral Reefs, *Stratigrafiya. Geologicheskaya Korrelyatsiya*, 1993, vol. 1, no. 3, pp. 3 - 8.

Bol'shakova, L.N., Gekker, M.R., Goryunova, R.V., Dubatolov, V.N. Ivanovskii, A.B., Kosmynin, V.N., Luchinina, V.A., Sokolov, B.S., and Tesakov, Yu.I., Paleozoic Coral Reefs in the Territory of Russia, *Stratigrafiya. Geologicheskaya Korrelyatsiya*, 1994, vol. 2, no. 1, pp. 46 - 55.

Copper, P., Enigmas in Phanerozoic Reef Development, *Mem. Assoc. Australas. Palaeontol.*, 1989, vol. 8, pp. 371 - 385.

Fisher, A., Two Phanerozoic Supercycles, *Katastrofy v Istorii Zemli* (Catastrophes in the Earth's History), Moscow: Mir, 1986, pp. 133 - 151.

Hofmann, P., Shallow and Deep-Water Stromatolites in Lower Proterozoic Platform-to-Basin Facies Change, Great Slave Lake, Canada, *AAPG Bull.*, 1974, vol. 58, pp. 856 - 867.

Joachimski, M. and Buggisch, W., Anoxic Events in the Frasnian Causes of the Frasnian-Famennian Faunal Crisis?, *Geology*, 1993, vol. 21, pp. 675 - 678.

Kuznetsov, V.G., Some Evolutionary Peculiarities of Reef-building in the Earth's History, *Evolyutsiya Osadochnogo Protsessa v Okeanakh i na Kontinentakh* (Development of the Sedimentary Process in Oceans and Continents), Moscow: Nauka, 1983, pp. 162 - 173.

Kuznetsov, V.G., The Carbonate Accumulation in Reefs and Its Evolution in the Earth's History, *Fanerozoiskie Rify i Korally SSSR* (The Phanerozoic Reefs and Corals of the USSR), Moscow: Nauka, 1986, pp. 110 - 123.

Manten, A., *Silurian Reefs of Gotland*, Amsterdam: Elsevier, 1971.

Poty, E., The Stratigraphy and Paleobiogeography of Belgian Visean Corals, *Acta Palaeontol. Polonica*, 1980, vol. 25, pp. 587 - 595.

Ronov, A.B., *Osadochnaya Obolochka Zemli: Kolichestvennye Zakonomernosti Stroeniya, Sostava i Evolutsii* (Sedimentary Cover of the Earth: Quantitative Characteristics of Structure, Composition, and Evolution), Moscow: Nauka, 1980.

Sando, W.J, The Paleoecology of Mississippian Corals in the Western Conterminous United States, *Acta Palaeontol. Polonica*, 1980, vol. 25, pp. 619 - 631.

Stanley, G.D., The History of Early Mesozoic Reef Communities: A Three Step Process, *Palaios*, 1988, no. 3, pp. 170 - 183.

Tektonika Evrazii (Tectonics of Eurasia), Moscow: Nauka, 1966.

Vail, P.R., Mitchum, J.R.,M., and Thompson, T.S., Seismic Stratigraphy and Global Changes of Sea Level, Part 4: Global Cycles of Relative Changes of Sea Level, *Seismic Stratigraphy – Application to Hydrocarbon Exploration*, Payton, C.E., Ed., Am. Ass. Petrol. Geol., 1977, Spec. Pap. no. 26, pp. 83 - 97.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 222 - 229. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 24 - 31.
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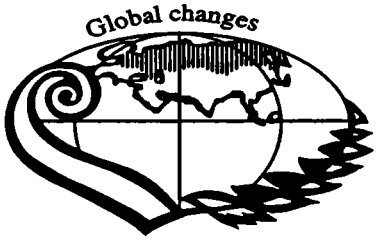

Evolution of the biosphere

The Most Important Global Sedimentological and Biological Devonian Events in Southern Tien Shan and the Southern Region of Western Siberia

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Abstract – Initially, the Devonian global biotic events were named according to their index taxa. Most often they are related to wide-scale transgressions. Later on, the same events were called by their own names according to lithostratigraphic subdivisions. We propose to transforming the double nomenclature of these global events into a single one, in which the proper name would correspond to the sedimentological event, and the index taxon would indicate its position within the standard stratigraphic scheme. Two new sedimentological events were established in the Lower Devonian, being at the same time the biological events as well: the Kyk (Praehercynicus) and Zinzilban (Dehiscens) events. The global biological event, which has two names, the Manticoceras or Frasnian Event, was also considered. Its stratigraphic level was defined more precisely and a new name was proposed, the Blauer Bruch Event (falsiovalis/norrisi), after the name of the quarry in Kellerwald (Germany), where this event is best displayed and after the index species that precisely define the biochronological level of the event.

The Devonian System differs from other Paleozoic systems in its abundance of known global events. They are considered extraordinary biological and sedimentological events that occurred on a planetary (or quasi-planetary) scale (Walliser, 1984, 1986a, b, 1990; House, 1985). Many of the sedimentological events have an anoxic nature. Physically, they are expressed by the synchronous appearance of black shales or dark-colored (carbonaceous) terrigenous-carbonate rocks.

Initially, attention was primarily paid to the elucidation and examination of biological events, and first all to events that are expressed as global extinctions in the Earth's history. Therefore, they were named according to the defining index taxon (Walliser, 1982, 1985), although the Frasnian–Famennian Event, one of the most prominent and first-established, got its name from the local stratigraphic subdivision (Kellwasser Event). At the same time, the attention was paid to the close relation between biologic and anoxic events and, often, to the relation between anoxic events and the beginning of wide-scale transgressions. It is possible that all of this was the basis for a wider use of names of local subdivisions in the nomenclature of what were actually only biotic events (House, 1985).

Thus, the new approach using the event names introduced in the literature, without their synonimyzation, for the creation of a scheme of global events, consisting of two indissolubly united parts. In this scheme, the names of index taxa correspond to those of the markers for the global tracing of biological events, and the names of stratigraphic subdivisions (or type localities) correspond to sedimentologic events. This allows us to distinguish the real relationship between the levels of the first appearance of event index taxon in specific geologic sequence and the sediments of the time-specific facies (TSF) (Walliser, 1986a; Walliser *et al.*, 1988).

For the Middle and Late Devonian, the global events that have been described were studied basically in detail, with the possible exception of one of them near the boundary between these stratigraphic subdivisions. But they were only outlined for the Lower Devonian (Walliser, 1985; Walliser *et al.*, 1988). Therefore we shall describe here the pre-Late Devonian and two new Early Devonian events on the basis of the data from southern Tien Shan and the southern region of Western Siberia.

KYK (PRAEHERCYNICUS) EVENT

This name came from the Kyk Horizon that includes the Andygen and Tillyaverdy beds and corresponds to the Upper Lochkovian and Pragian of the Standard Stratigraphic Scale (Yolkin and Kim, 1988). The stratotype of this horizon is situated in Southern Fergana, in the basin of the middle reaches of the Isfara River. This outcrops on the northeastern slope of Mt. Kyk, where the continuous sequence of the strata from the Pridolian to the Lower Carboniferous is observed (Fig. 2 in Kim *et al.*, 1988). The sequence is unique because its Lochkovian-Pragian part is represented by the alternation of limestone with shell remains and shales with graptolites. A favorable combination of pelagic and neritic faunal groups allowed the full succession of the graptolitic zones to be established and compared with the subdivision based on benthic fauna (Erina *et al.*, 1976; Koren', 1978; Koren' and Klishevich, 1982; Kim *et al.*, 1982, 1988).

The event-level under consideration corresponds to the lower boundary of the Kyk Horizon that is related to the sharp transition from limestones of the Sarysait

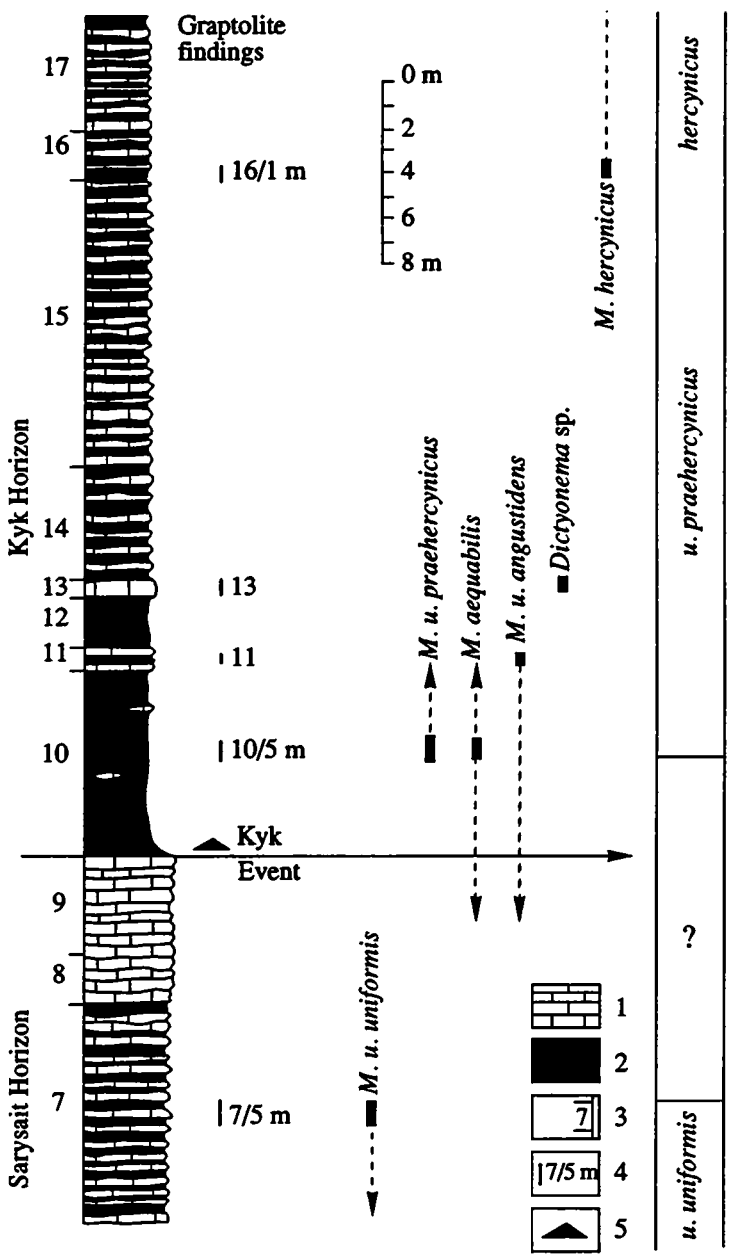

Fig. 1. Graptolite distribution in the boundary layers of the Sarysait and Kyk horizons in the sedimentary sequence on the right bank of the middle reaches of the Isfara River, Southern Fergana, Southern Tien Shan, Kirghizia.

1 – dark gray limestone; 2 – black shale; 3 – layer number; 4 – sampling interval and index of paleontological sample; 5 – locality of event. Graptolite-based zonation is given on the right.

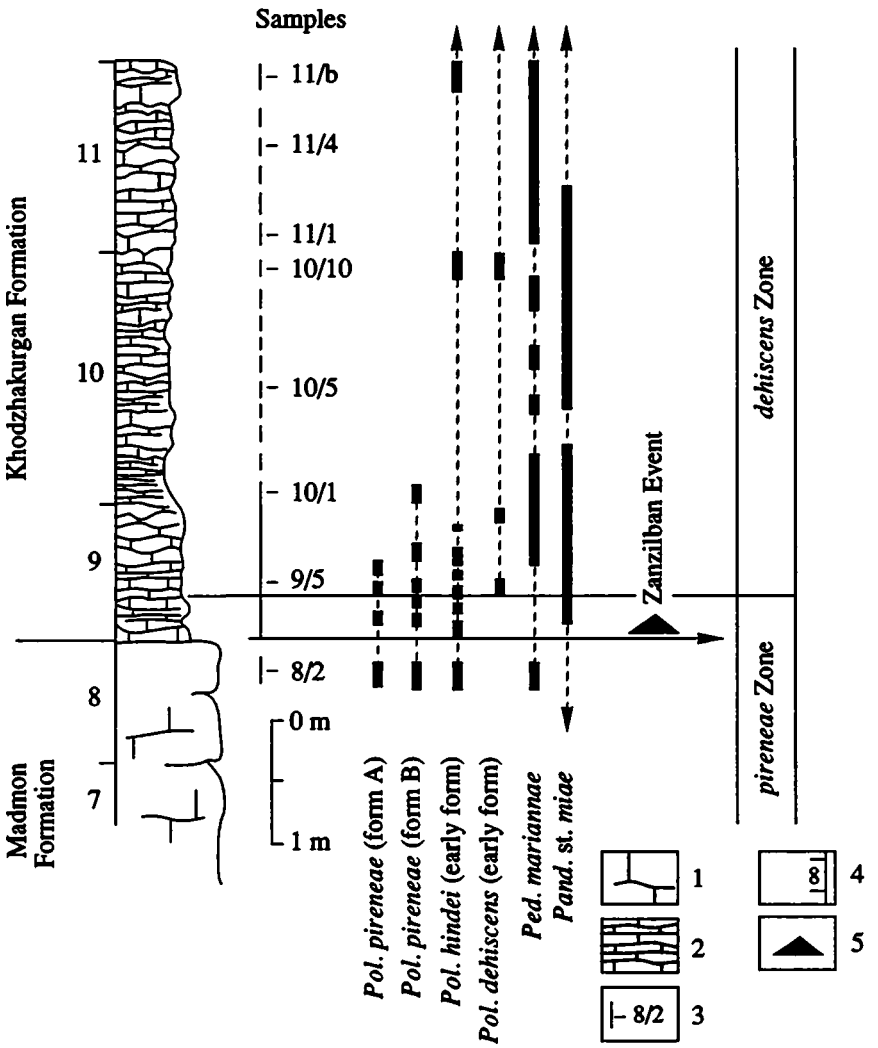

Fig. 2. Conodont distribution in the boundary layers of the Madmon and Khodzhakurgan formations in the sedimentary sequence along the Zinzilban Gorge, the Dzhindydar'ya River Basin, Zeravshan Ridge, Southern Tien Shan, Uzbekistan.

1 – Massive limestone; 2 – bedded limestone; 3, 4, and 5 – see legend in Fig. 1. Conodont-based zonation is given on the right.

Horizon (Fig. 1, layers 7 - 9) to clayey and clayey-siliceous shales (Fig. 1, layers 10 - 17), which mark the beginning of a large transgression. The transgressive succession of the layers of the Kyk Horizon is apparent in a number of sequences from Mt. Kyk westward to the Isfara River, where the facies changes at that level are represented very clearly. Black shales occur there on the upper unit of the Sarysait Horizon containing large bodies of algal bioherms (Kim *et al.*, 1988).

Changes in the faunal assemblage compositions are very significant at the level under consideration. But they do not look very impressive in the published data available on Southern Tien Shan (Kim *et al.* 1982, 1988; Rzhonsnitskaya *et al.* 1982, and others) because they include only part of the information and some collected material has not yet been examined monographically.

Better-displayed biotic changes at the level of the Kyk Event can be observed in the sequences in the southern region of Western Siberia. At this location, the Kyk event level corresponds to the boundary between the Kaibal'sk and Beltir Regional Stages (Yolkin *et al.*, 1982, 1983) and relates to the beginning of a large transgression as well. The Lower Devonian sequence is rather uniform and consists of carbonate rocks in Salair (Yolkin, 1968). Therefore the synchronous changes in the composition of different faunal assemblages found there at the level of the Kyk Event (Tables 9 - 11 in Yolkin *et al.* 1983) are without a doubt evolutionary and extraordinary. This data is very important for the understanding of the scale of the Kyk Event because here, unlike in other regions of the world, the two sedimentary cycles (Kaibal'sk and Beltir), related to the eustatic sea level fluctuations, are displayed very clearly in the lower part of the sequence (Talent and Yolkin, 1987).

The subspecies *Monograptus uniformis praehercynicus* Jaeger is proposed as the index taxon of the Kyk Event. In the stratotypic section of the event this sub-

species appears at a level 5 m above the lower boundary of the Kyk Horizon. This is a good approximation of the level of the sedimentologic event: the appearance of black shales in the transgressive sedimentary member. It is important to emphasize that, judging by its large thickness this sequence is not condensed.

The subspecies *M. uniformis praehercynicus* was described first as a species, and an independent zone between the *uniformis* and *hercynicus* Zones was established on this basis (Jaeger, 1959). Subsequently these three zones were cited in a number of publications as a zonal scale for the Lochkovian (Berry, 1970, 1973; Jagger, 1979, 1988, and others). The *praehercynicus* Zone is absent in other publications. Its index form is placed either in the assemblage of the *hercynicus* Zone (Koren', 1969, 1971; Koren' and Klishevich, 1982, and others) or the graptolitic assemblage of the *uniformis* Zone (Obut, 1974; Kim *et al.*, 1988; Sennikov, 1990). In Arctic Canada, the *praehercynicus* Zone is not defined (Lenz, 1988). In Poland, the distribution range of *M. praehercynicus* corresponds to the upper part of the *uniformis* Zone and the lower part of the *hercynicus* Zone (Fig. 19 in Porebska, 1984).

Analyzing all of the published data, one is easily convinced that the subspecies *M. uniformis praehercynicus* appears earlier than *M. hercynicus*. However, both of them, as well as *M. uniformis uniformis*, have an overlapping distribution range. This allows the appearance of *M. uniformis praehercynicus* to be considered as an innovative biologic event directly following the beginning of a large transgression, which is marked by the Kyk sedimentologic event (Fig. 1).

ZINZILBAN (DEHISCENS) EVENT

The event was named after the Zinzilban Beds that comprise the lower part of the Kitab Horizon or the Khodzhakurgan Formation. The type section of these beds (and the event) crops out on the Zeravshan Ridge of Southern Tien Shan, along the Zinzilban Gorge, which is situated in the Kitab State Geological Reserve. It was here that the International Subcommission on Devonian Stratigraphy (SDS) determined the Global Stratotype Section and Point (GSSP) of the lower boundary of the Emsian Stage of the Standard Stratigraphic Scale. The reference level of that boundary is marked by the first appearance of *dehiscens* (Yolkin *et al.*, 1989; Fig. 2). This level is located 35 cm above the boundary between the Madmon and Khodzhakurgan formations. The former is represented principally by massive limestone more than 1-km-thick and corresponds to the Lochkovian and Pragian. The later consists of layered clayey limestone with minor interlayers of shales and is dated as the Emsian and Eifelian in the vicinity of Zinzilban Gorge. Only a 35 cm basal layer of the Khodzhakurgan Formation still belongs to the Pragian, according to the decision of the SDS. They are excluded from the Zinzilban Beds and the Kitab Horizon, respectively (Yolkin and Kim, 1988).

The level of the Zinzilban Event corresponds to the boundary between the formations under consideration that is expressed as a rather sharp transition from light, massive or vaguely bedded limestones to black, tabular clayey limestones. Both varieties of the limestones contain only rare fragments of macrofauna in this transitional interval (Kim *et al.*, 1978, 1984). However, key forms of conodonts were found there (Yolkin *et al.*, 1989; Fig. 2). For example, numerous *Polygnathus pireneae* Boersma were encountered in the uppermost part of the Madmon Formation (Fig. 2, Layer 8, interval 2), and *Eognathodus sulcatus kindlei* Lane et Ormiston was found about 20 m below the boundary of the formations, in Layer 3. The occurrence of *P. dehiscens* Philip in interval 5 of Layer 9 together with *P. pireneae* Boersma clearly fixes the lower boundary of the Emsian and the first bed of the transgressive sedimentary unit, which is still within the *pireneae* Zone.

The transgressive event at the boundary between the Pragian and Emsian is well-expressed in many regions of the world. The event has already been discussed in publications, in particular, in relation to the eustatic sea level fluctuations (Johnson *et al.*, 1985; Johnson and Sandberg, 1988; Talent and Yolkin, 1987). This event was also correlated to the Zlikhov transgression and named the Zlikhov Event (House, 1985).

The Zinzilban Even is expressed in the Devonian sequences of the Salair and Altai Mountains as clearly as in the type section. The facies transition there is displayed still sharper. In Salair, massive reefal limestone changes into dirty-green and dark shale, siltstone and limestone with plant remains and normal marine fauna (*Stratotipicheskie Razrezy* ..., 1986). In Altai, the same reefal limestone is overlain by a unit of predominantly terrigenous rocks, which has a basal conglomerate at its base in Central Altai (Yolkin, 1968).

The biotic changes at the Zinzilban Event level can be compared, in scale, to the largest analogous Devonian changes recorded near the Givetian–Frasnian and even Frasnian–Famennian boundaries. Both a mass extinction of benthic organisms (Yolkin *et al.*, 1982) and the innovations that followed (Yolkin; 1967, Yolkin; 1968; Yolkin *et al.*, 1989) belong to these changes.

P. dehiscens, the index species of the lower boundary of the Emsian of the Standard Stratigraphic Scale, is the biochronological marker of the Zinzilban Event. Its first appearance at a level of 35 cm above the stratum corresponding to the beginning of the transgression (Fig. 2) could indicate that the following innovative event experienced a certain delay in relation to the transgression. However, the appearance of another innovatory element in the polygnathic phylogenetic line, *P. hindei* Apekina, below that stratum (Fig. 2) means that innovations are not directly conditioned by the transgression and may precede it. Nevertheless, the experience demonstrates that the events related to extinctions, innovations, as well as the global transgressions are part of a single chain of global events (Walliser, 1985, 1986a, b), the primary reason of which is

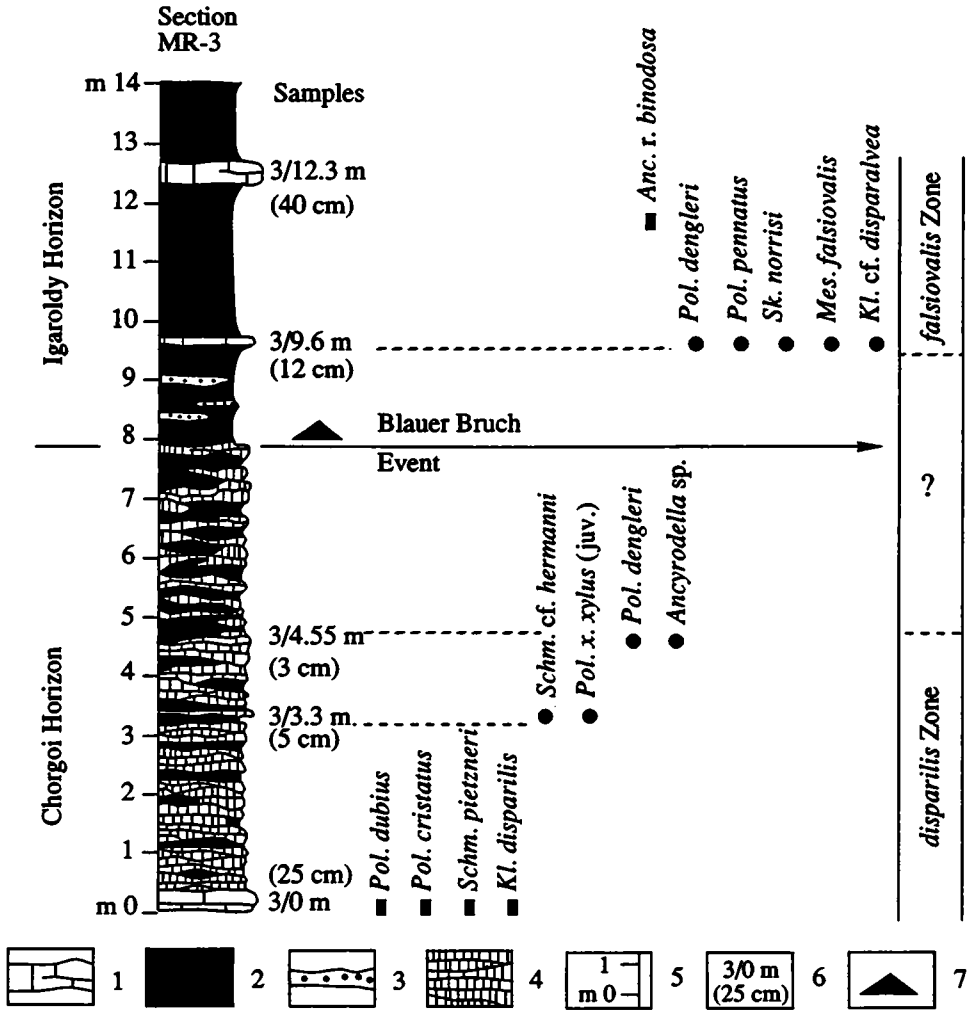

Fig. 3. Conodont distribution in the boundary layers of the Chorgoi and Igaroldy horizons in the sedimentary sequence along the Igaroldy Gorge, the right bank of the middle reaches of the Isfara River, Southern Fergana, Southern Tien Shan, Kirghizia.

1, 2, and 7 – see legend in Fig. 1; 3 – siltstone; 4 – green cherts; 5 – 1 m from the section base; index of paleontological sample and sampling interval in cm. Conodont-based zonation is given on the right.

most likely complex and includes both cosmic and terrestrial factors.

BLAUER BRUCH EVENT (OR FALSIOVALIS/NORRISI)[1]

This event was initially named after the index taxon as the Manticoceras Event (Walliser, 1985). The proper name, the Frasnian Event, was also applied to this event (House, 1985). In both cases, the same time-boundary, to which the global transgression is related, is implied. In northeastern Alberta (Canada), this is called "the Transgressive Waterways Event" (Braun *et al.*, 1988), and in Southern Fergana, the same boundary, which we defined in 1987, was called "the Igaroldy (Norroisi) Event" (Yolkin *et al.*, 1992).

The analysis of the current situation shows that Walliser put forward solid grounds to reject the name proposed by House. At the same time, Walliser's arguments to adopt the name "the Manticoceras Event" are not very convincing. The appearance of this taxon and the beginning of the global transgression are quite separated chronologically. Therefore, it is not easy to use infrequent finds of *Manticoceras*, in practical terms, for dating the transgressive event-level. Moreover, the Manticoceras Event occupies a special place in the list of the most important events of the ammonoids evolution.

A detailed examination of the boundary layers of the Frasnian and Famennian in the "Blauer Bruch" locality (Lottmann *et al.*, 1986; Sandberg, 1989; Ebert, 1992), previously published data from Morocco (Bensaid, 1985),

[1] Prof. O.H. Walliser, in his letter dated by July 8, 1993, informed us that his graduate student J. Ebert has examined this event-level on the basis of data from Ense (Germany). The Blauer Bruch section, which we adopted as a type section, is situated at that place. Ebert called this "the Ense Event" in the paper, which has certainly already been published. We recognize the "Ense" name, but were unable to make the corresponding correction because the paper is not yet available.

and the compete revision of the standard conodont zonal scale (Ziegler and Sandberg, 1990) affords the chance to look at this problem in the other way. When solving this problem, the "Blauer Bruch" section acquires key importance because the beginning of the transgression is precisely documented by the first appearance of the new zonal index-species *Mesotaxis falsiovalis* Sandb., Zieg. et Bult. co-occurring with the previous index-species *Skeletognathus norrisi* of the *Lowermost asymmetricus* Zone. That is why we decided to digress from the norm and to name this the Blauer Bruch Event, after the reference section locality.

This event is well-expressed, but does not contrast, with respect to facies, to the section along the Igaroldy Gorge (Fig. 3). A member of green jasper is changed by black shale and silicious shale rich in silt at the base. Thin layers or lenses of predominantly dark fine-grained limestone, usually without macrofauna remains, occur inside the jasper/shale member. Conodonts were found in the limestone, which allows the *disparilis* and *falsiovalis* zones to be distinguished (Fig. 3). Because of the absence of carbonate rocks, an approximately 4.5 m interval was not characterized palieontologically.

We relate the level of the disappearance of jasper and the appearance of siltstone in the shale member to the beginning of the transgression and, accordingly, the Blauer Bruch Event. The index species of the event, *falsiovalis* and *norrisi*, were found 1.7 m upsection of that level. Noteworthy is *Ancyrodella* sp., which is included in an interval of the *disparilis* Zone (Fig. 3). This form is represented by the only small specimen. Its main peculiarity is a rather broad basal cavity with straight margins from the central wide part to the back end of the element. This feature looks relatively ancient and differs in form from the rest of ancyrodells, including the young specimen of *Ancyrodella* sp. described from the interval of the *falsiovalis* Zone in the Blauer Bruch section (Sandberg *et al.*, 1989).

Traces of the Blauer Bruch transgression in Russia are best displayed in the Devonian sequences on the eastern margin of the Russian platform and in the western slope of the Urals. Its beginning corresponds to the base of the Pasha Horizon, which was traditionally included in the Upper Devonian. This is the stratigraphic level that was thought to be the beginning of the principal biotic reorganizations in different groups of fauna and flora (*Stratigrafiya SSSR*, 1973).

Sequences, where it would be possible to confirm paleontologically the presence of the Blauer Bruch Event, are not found yet in the southern region of Western Siberia. At some places (southeastern Altai and Minusa), red beds are represented in this stratigraphic interval, which indicate only a sharp change in sedimentation conditions. Other areas of the distribution of the Givetian–Frasnian boundary deposits have either a complex geologic structure or a special, so called black shale type of the sequence, which needs additional examination.

It should be noted in conclusion that other known global Devonian events are also recorded in the territory of the former USSR. The three events described above are the principal ones. They correspond to the stratigraphic levels that were adopted in all regions according to the unified schemes as the boundaries of series (Zanzilban and Blauer Bruch Events) or stages (Kyk Event). Therefore their more precise localization relative to the standard stratigraphic scales based on conodonts and graptolites will promote a more precise definition of the global correlations of sedimentary members and the clarification of general principles of wide-scale reorganizations in the biosphere.

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REFERENCES

Bensaid, M., Bultynsc, P., Sartenaer, P., Walliser, O.H., and Ziegler, W., The Givetian–Frasnian Boundary in pre-Sahara Morocco, *Cour. Forsch. Inst. Senckenberg* (Frankfurt am M.), 1985, vol. 75, pp. 287 - 300.

Berry, W.B.N., The Base of the Devonian and an Early Devonian Graptolite Succession in Central Nevada, *Bull. Geol. Soc. America*, 1970, vol. 81, pp. 513 - 520.

Berry, W.B.N., Silurian–Early Devonian Graptolites, *Atlas of Palaeobiogeography*, Amsterdam: Elsevier, 1973, pp. 81 - 87.

Braun, W.K., Norris, A.W., and Uyeno, T.T., Late Givetian to Early Frasnian Biostratigraphy of Western Canada: The Slave Point–Waterways Boundary and Related Events, *Devonian of the World: Paleontology, Paleoecology, and Biostratigraphy*, McMillan, N.Y., Embry, A.F., and Glass, D.J., Eds., Calgary, Alberta, Canada: Can. Soc. Petrol. Geol., 1988, Mem. 14, vol. 3, pp. 93 - 111.

Ebert, J., Events around the Pharciceras Stufe, Phanerozoic Bio-Events and Event-Stratigraphy. Abstracts of Papers, *5th Int. Conf. on Bio-Events*, Gottingen, 1992, pp. 128 - 129.

House, M.R., Correlation of Mid-Palaeozoic Ammonoid Evolutionary Events with Global Sedimentary Perturbations, *Nature*, 1985, vol. 313, no. 3, pp. 17 - 22.

Jaeger, H., Graptolithen und Stratigraphie des Jungsten Thuringer Silurs, *Abhandl. Deutsch. Akad. Wiss. Berlin. Chemie, Geologie und Biologie*, Jahrang, 1959, no. 2.

Jaeger, H., Devonian Graptolithina, Devonian System, *Special Papers in Palaeontology*, 1979, vol. 23, pp. 335 - 339.

Jaeger, H., Devonian Graptoloidea, *Devonian of the World: Paleontology, Paleoecology, and Biostratigraphy*, McMillan, N.Y., Embry, A.F., and Glass, G.J., Eds., Calgary, Alberta, Canada: Can. Soc. Petrol. Geol., 1988, Mem. 14, vol. 3, pp. 431 - 438.

Johnson, J.G., Klapper, G., and Sandberg, Ch.A., Devonian Eustatic Fluctuations in Euroamerica, *Bull. Geol. Soc. Am.*, 1985, vol. 96, pp. 567 - 587.

Johnson, J.G. and Sandberg, Ch.A., Devonian Eustatic Events in the Western United States and Their Biostratigraphic Responses, *Devonian of the World: Paleontology, Paleoecology, and Biostratigraphy*, McMillan, N.Y.,

Embry, A.F., and Glass, D.J., Eds., Calgary, Alberta, Canada: Can. Soc. Petrol. Geol., 1988, Mem. 14, vol. 3, pp. 171 - 178.

Kim, A.I., Erina, M.V., Yolkin, E.A., and Sennikov, N.V., Subdivision and Correlation of the Devonian of South Fergana (Turkestano-Alai Mountain Area, USSR), *Devonian of the World: Paleontology, Paleoecology, and Biostratigraphy*, McMillan, N.Y., Embry, A.F., and Glass, G.J., Eds., Calgary, Alberta, Canada: Can. Soc. Petrol. Geol., 1988, Mem. 14, vol. 3, pp. 703 - 714.

Kim, A.I., Yolkin, E.A., and Erina, M.V., Biostratigraphy of the Lower and Middle Devonian of Middle Asia, *Biostratigrafiya Pogranichnykh Otlozhenii Nizhnego i Srednego Devona. Trudy Polevoi Sessii Mezhdunarodnoi Podkomissii po Stratigrafii Devona, Samarkand, 1978* (Biostratigraphy of the Boundary Deposits of the Lower and Middle Devonian. Proc. of the Field Session of the Int. Subcommission on Devonian Stratigraphy, Samarkand, 1978), Leningrad: Nauka, 1982, pp. 85 - 92.

Kim, A.I., Yolkin, E.A., Erina, M.V., and Gratsianova, R.T. *Tipovye Razrezy Pogranichnykh Sloev Nizhnego i Srednego Devona Srednei Azii. Putevoditel' Ekskursii* (Type Sections of the Boundary Layers of the Lower and Middle Devonian of Middle Asia. Field Excursion Guide), Tashkent: Polevaya Sessiya Mezhdunarodnoi Podkomissii po Stratifrafii Devona, Samarkand, 1978.

Kim, A.I., Yolkin, E.A., Erina, M.V., Korsakov V.S., and Tsoi, R.V., Excursion 100. Middle Paleozoic of Southern Tien Shan. Uzbek Soviet Socialist Republic. Excursions: 033, 035, 088, 100. Summary Excursion Guide, *Mezhdunarodnyi Geologicheskii Kongress, XXVII Sessiya, SSSR, 1984* (Int. Geological Congr., XXVII Session, USSR, 1984), Tashkent: Fan, 1984, pp. 138 - 166.

Koren', T.N., The Upper Boundary of the *Monograptus hercynicus* Zone in Pai-Khoi and Its Paleontological Ground, *Dokl. Akad. Nauk SSSR, Ser. Geol.*, 1969, vol. 189, no. 6, pp. 1325 - 1328.

Koren', T.N., The Zones of *Monograptus hercynicus* and *Monograptus falcarius* in Pai-Khoi, *Lethaia*, 1971, vol. 4, no. 2, pp. 235 - 248.

Koren', T.N., Early Devonian Graptolites of South Fergana, Central Asia, *Casopis Mineralogii, Geologii*, 1978, vol. 23, no. 2, pp. 113 - 127.

Koren', T.N. and Klishevich, V.L., Biostratigraphic Subdivision of the Devonian Reference Sections of Middle Asia on the Basis of Graptolites and Dacrioconarids, *Biostratigrafiya Pogranichnykh Otlozhenii Nizhnego i Srednego Devona. Trudy Polevoi Sessii Mezhdunarodnoi Podkomissii po Stratigrafii Devona, Samarkand, 1978* (Biostratigraphy of the Boundary Deposits of the Lower and Middle Devonian. Proc. of the Field Session of the Int. Subcommission on Devonian Stratigraphy, Samarkand, 1978), Leningrad: Nauka, 1982, pp. 93 - 97.

Lenz, A.C., Revision of Upper Silurian and Lower Devonian Graptolite Biostratigraphy and Morphological Variation in *Monograptus yukonensis* and Related Devonian Graptolites, Northern Yukon, Canada, *Devonian of the World: Paleontology, Paleoecology, and Biostratigraphy*, McMillan, N.Y., Embry, A.F., and Glass, D.J., Eds., Calcary, Alberta, Canada: Can. Soc. Petrol. Geol., 1988, Mem. 14, vol. 3, pp. 439 - 447.

Lottmann, J., Sandberg, Ch.A., Schindler, E., Walliser, O.H., and Ziegler, W., Devonian Events at Ense Area (Excursion to the Rheinisches Schiefergebirge), *Global Bio-Events. A Critical Approach*, Walliser, O.H., Ed, Lecture Notes in Earth Sciences, Bhattachrji, S., Friedman, G.M., Neugebauer, H.J, and Seilacher, A., Eds., Springer, 1986, vol. 8, pp. 17 - 21.

Stratigrafiya SSSR. Devonskaya Sistema (Stratigraphy of the USSR. Devonian System), Nalivkin, D.V., Rzhonsnitskaya, M.A., and Markovskii, B.P., Eds., Books 1 and 2, Moscow: Nedra, 1973.

Obut, A.M., *Nizhnedevonskie Graptolity v Srednei Azii* (Lower Devonian Graptolites in Middle Asia), Novosibirsk: Nauka, 1974.

Porebska, E., Latest Silurian and Early Devonian Graptolites from Zdanov Section, Bardo Mts (Sudetes), *Ann. Soc. Geol. Poloniae*, 1984, vol. 52, nos. 1 - 4, pp. 89 - 209.

Rzhonsnitskaya, M.A., Kulikova, V.F., and Petrosyan, N.M., Sections of the Lower and Lower Middle Devonian in Southern Fergana, *Biostratigrafiya Pogranichnykh Otlozhenii Nizhnego i Srednego Devona. Trudy Polevoi Sessii Mezhdunarodnoi Podkomissii po Stratigrafii Devona, Samarkand, 1978* (Biostratigraphy of the Boundary Deposits of Lower and Middle Devonian. Proc. of the Field Session of the Int. Subcommission on Devonian Stratigraphy, Samarkand, 1978), Leningrad: Nauka, 1982, pp. 123 - 129.

Sandberg, Ch.A., Ziegler, W., and Bultynck, P., New Standard Conodont Zones and Early Ancyrodella Phylogeny across Middle-Upper Devonian Boundary. Contributions to Devonian Paleontology and Stratigraphy. Part II: Various Devonian Topics, Walliser, O.H. and Ziegler, W., Eds., *Cour. Forsch.-Inst. Senckenberg*, 1989, vol. 110, pp. 195 - 229.

Sennikov, N.V., New Look at Systematics of Early Devonian Monopraptides, *Novoe v Paleontologii i Biostratigrafii Aziatskoi Chasti SSSR* (News in Paleontology and Biostratigraphy in the Asian Part of the USSR), Novosibirsk: Nauka, 1990, pp. 58 - 71.

Stratotipicheskie Razrezy Nizhnego i Srednego Devona Salaira. Telengitskii Nadgorizont: Terrigenno-Karbonatnye Fatsii (Stratotypic Sections of the Lower and Middle Devonian of Salair. The Telenga Superhorizon: Terrigenous-Carbonate Facies), Novosibirsk: IGiG SO Akad. Nauk SSSR, 1986.

Talent, J.A. and Yolkin, E.A., Transgression–Regression Patterns for the Devonian of Australia and South West Siberia, *Cour. Forsch. Inst., Senckenberg*, 1987, vol. 92, pp. 235 - 249.

Walliser, O.H., Goniatide-Based Correlation of the Boundary of the Lower and Middle Devonian, *Biostratigrafia Pogranichnykh Otlozhenii Nizhnego i Srednego Devona. Trudy Polevoi Sessii Mezhdunarodnoi Podkomissii po Stratigrafii Devona, Samarkand, 1978* (Biostratigraphy of the Boundary Deposits of the Lower and Middle Devonian. Proc. of the Field Session of the Int. Commission on Devonian Stratigraphy, Samarkand, 1978), Leningrad: Nauka, 1982, pp. 51 - 53.

Walliser, O.H., Geologic Processes and Global Events, *Terra Cognita*, Paris, 1984, vol. 4, pp. 17 - 20.

Walliser, O.H., How to Define "Global Bio-Events," *Extinction Events in Earth History*, Kauffman, E.G. and Walliser. O.H., Eds., Lecture Notes in Earth Sciences, Bhattachrji, S., Friedman, G.M., Neugeubauer, H.J., and Seilacher, A., Eds., Springer, 1990, vol. 30, pp. 1 - 3.

Walliser, O.H., Natural Boundaries and Commission Boundaries in the Devonian. Morocco, *Cour. Forsch.-Inst. Senckenberg*, 1985, vol. 75, pp. 401 - 407.

Walliser, O.H., The IGCP Project 216 "Global Biological Events in Earth History," Global Bio-Events. A Critical Approach, Walliser, O.H., Ed., *Lecture Notes in Earth Sciences*, Bhattachrji, S., Friedman, G.M., Neugeubauer, H.J., and Seilacher, A., Eds., Springer, 1986, vol. 8, pp. 1 - 4.

Walliser, O.H., Towards a More Critical Approach to Bio-Events, *Global Bio-Events. A Critical Approach*, Walliser, O.H., Ed., Lecture Notes in Earth Sciences, Bhattachrji, S., Friedman, G.M., Neugeubauer, H.J., and Seilacher, A., Eds., Springer, 1986, vol. 8, pp. 5 - 16.

Walliser, O.H., Lottmann, J., and Schindler, E., Global Events in the Devonian of the Kellerwald and Harz Mountains, Part 1. Guide to Field Trips, Ziegler, W., Ed., *Cour. Forsch.-Inst. Senckenberg*, 1988, vol. 102, pp. 190 - 193.

Yolkin, E.A., Trilobite and Lower-Middle Devonian Boundary in Southwestern Siberia, *Proc. Int. Symp. on the Devonian System*, Calgary, 1967, vol. 2, pp. 981 - 989.

Yolkin, E.A., *Trilobity i Stratigrafiya Nizhnego i Srednego Devona Yuga Zapadnoi Sibiri* (Trilobites and Stratigraphy of the Lower and Middle Devonian of South Western Siberia), Moscow: Nauka, 1968.

Yolkin, E.A., *Zakonomernosti Evolutsii Dakhenellid i Biokhronologiya Silura i Devona* (Evolutional Trends of Dachenellids and Biostratigraphy of Silurian and Devonian), Moscow: Nauka, 1983.

Yolkin, E.A., Apekina, L.S., Erina, M.V., Izokh, N.G., Kim, A.I., Talent, J.A., Walliser, O.H., Weddige, K., Werner, R., and Ziegel, W., Polygnathid Lineages across the Pragian-Emsian Boundary. Zinzilban Gorge, Zerafshan, USSR, *Contributions to Devonian Paleontology and Stratigraphy, Part II: Various Devonian Topics*, Walliser, O.H. and Ziegel, W., Eds., *Cour. Forsch.-Inst. Senckenberg*, 1989, vol. 110, pp. 327 - 145.

Yolkin, E.A., Gratsianova, R.T., Zheltonogova, V.A., and Kim, A.I., Principal Biostratigraphic Boundaries and Subdivisions of the Lower and Middle Devonian in the Western Altai–Sayans Region and their Correlation, *Biostratigrafiya Pogranichnykh Otlozhenii Nizhnego i Srednego Devona, Trudy Polevoi Sessii Mezhdunarodnoi Podcomissii po Stratigrafii Devona, Samarkand, 1978* (Biostratigraphy of the Boundary Deposits of Lower and Middle Devonian, Proc. of the Field Session of the Int. Subcommission on Devonian Stratigraphy, Samarkand, 1978), Leningrad: Nauka, 1982, pp. 65 - 80.

Yolkin, E.A. and Kim, A.I., Devonian of the Asiatic Part of the USSR: Recent Achievements and Problems, *Devonian of the World: Paleontology, Paleoecology, and Biostratigraphy*, McMillan, N.Y., Embry, A.F., and Glass, D.J., Eds., Calgary, Alberta, Canada: Can. Soc. Petrol. Geol., 1988, Mem. 14, vol. 3, pp. 663 - 667.

Yolkin, E.A., Talent, J.A., and Kim, A.I., Sedimentary, Biologic and Geologic Events in the Devonian of Siberia, Abstracts of Papers, *Central Asia and Australia, V Intern. Conf. on Bio-Events*, Gottingen, 1992, p. 122.

Ziegler, W. and Sandberg, Ch.A., The Late Devonian Standard Conodont Zonation, *Cour. Forsch. Inst. Senckenberg*, 1990, vol. 121.

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The Carboniferous–Permian Boundary in Stratotype Sections of the South Urals and Its Correlation

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Abstract – Resolutions passed by the Interdepartment Stratigraphic Committee of Russia approved the decision of the Plenary Session of the Commission on the Permian and Carboniferous Systems in terms of the Carboniferous–Permian boundary and the stratotype of this boundary (the Aidaralash section in the Aktyubinsk Region, Kazakhstan). A detailed description of this section and the distribution of the most important faunal groups there, such as fusulinids, ammonoids, and conodonts is given. They provide the biostratigraphic and paleomagnetic substantiation of this boundary. The Aidaralash section is offered as a global stratotype of the Carboniferous–Permian boundary. The above faunas and paleomagnetic data are used to correlate the boundary deposits with stratigraphic sections in the Arctic region, Donets Basin, Central Asia, Western Europe, North America, China, and Japan.

On March 9, 1992, the Interdepartment Stratigraphic Committee of Russia approved the resolutions passed on June 12, 1990 by the joint plenary session of its Commissions on the Permian and Carboniferous Systems. The resolution established the Carboniferous-Permian boundary in Russia and, respectively, the lower boundary of the Asselian Stage. The latter was officially fixed in the goniatite scale between the *Shumardites–Vidrioceras* and *Svetlanoceras–Juresanites* zones. It coincides with the boundary of the *Ultradaixina bosbytauensis–Schwagerina robusta* and *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* fusulinid zones. The stratotype of the boundary was established in the Aidaralash section between strata 19/5 and 20 (*Postanovleniya* ..., 1992).

The adopted resolutions summarized the results of long term studies initiated in the 1960s by a large group of experts on fusulinids. The group was headed by G.D. Kireeva (Kireeva *et al.*, 1971). Later on, the research was continued by other scientists (Rauzer-Chernousova, 1976; Rauzer-Chernousova and Shchegolev, 1980; Pnev *et al.*, 1975, 1978; Bensh, 1982; Kalmykova, 1984; *Postanovleniya* ..., 1984; *Pogranichnye Otlozheniya* ..., 1986; Popov *et al.*, 1985, 1989; Davydov, 1987, 1990; Leven and Shcherbovich, 1978; Leven and Davydov, 1979; Davydov *et al.*, 1990, 1992; and others). Traditionally, the Carboniferous–Permian boundary in this country was defined according to fusulinids.

Beginning with 1984, experts on fusulinids discussed three versions of this boundary in the fusulinid scale: (a) at the base of the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone (the top of the *Daixina sokensis* Zone); (b) at the base of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* (s. str.) Zone; (c) at the base of the *Sphaeroschwagerina moelleri–Pseudofusulina fecunda* Zone.

In 1987, the International Subcommission on Permian Stratigraphy organized the Working Group on the Carboniferous–Permian Boundary. It was headed by Professor Wu Wang-shi from the Nanking Institute of Geology and Paleontology. Members of this Working Group also discussed the above versions of the boundary in the fusulinid scale (*Permophiles* ..., 1990, 1992). They decided that the classical Upper Carboniferous–Lower Permian sections in the South Urals were the most useful sections in solving the problem of the Carboniferous–Permian boundary. At the International Congress "Permian Deposits of the World," which took place in Perm' in 1991, Russian experts put forth their suggestion on the Carboniferous–Permian boundary and its stratotype (Davydov *et al.*, 1992). The majority of the Working Group's members accepted that suggestion (*Permophiles*, no. 21, 1992). However, the final decision on this boundary will be taken after additional studies of the sedimentation conditions of the boundary deposits and verification of the conodont distribution in the Aidaralash section. The necessary field studies were conducted in the summer of 1993 by scientists from the All-Russian Geological Institute, Paleontological Institute of the Russian Academy of Sciences, Ekaterinburg Institute of Geology and Geochemistry of the Russian Academy of Sciences, Boise State University, and Brigham Young University.

As was mentioned above, the 1990 Plenary Session of the ISC on the Permian–Carboniferous Systems considered three versions of their boundary position.

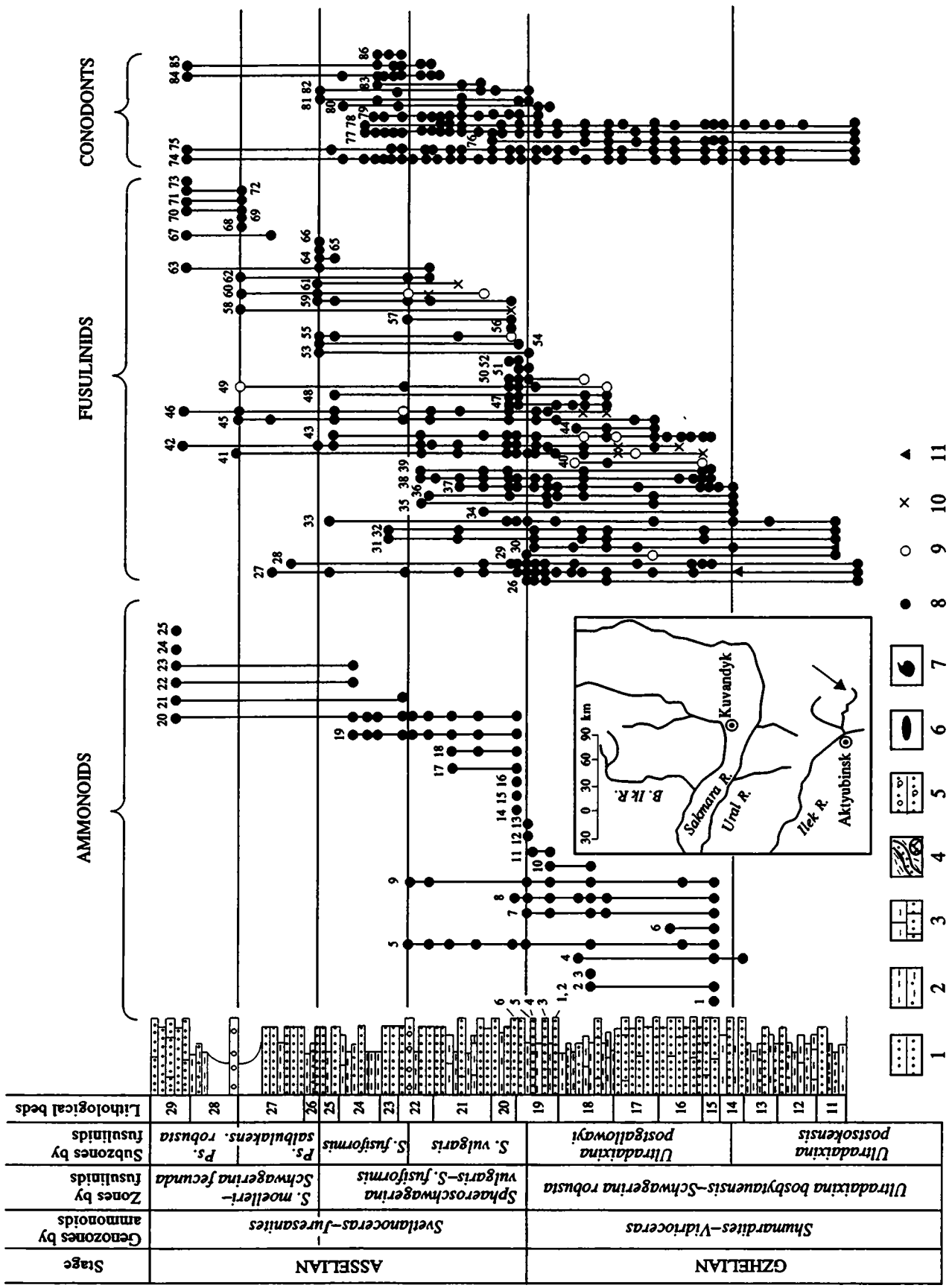
The Plenary Session also listened to reports on preliminary special colloqia on conodonts, fusulinids, and ammonoids. The obtained results were thoroughly discussed. The boundary was finally fixed between the *Shumardites–Vidrioceras* and *Svetlanoceras–Juresanites* ammonoid zones. In the fusulinid scale, this level corresponds to the lower boundary of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* (s. str.) Zone. The main arguments favoring such decision are as follows. This boundary meets the standard suggested by Ruzhentsev (1936), who established the base of the Asselian Stage in the South Urals exactly at this level more than fifty years ago. This boundary reveals distinct changes in the assemblages of the three leading fossil groups, namely ammonoids, fusulinids, and conodonts. All three undergo distinct change, which are practically simultaneous, though of different scales. As a result, the accepted boundary is of great correlational potential and can be traced globally. The boundary, coinciding with the base of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone, is widely used in the literature. During the last decade, the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone was frequently mentioned by scientists who also included into its volume the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. As a result, the boundary was actually identified at a lower level, though its formal definition did not change. Finally, it is also very important that this boundary is sufficiently well fixed in a section of the stratotype region (the Aidaralash Creek, Aktyubinsk Region, Kazakhstan).

THE AIDARALASH SECTION

The Aidaralash section is situated on the right bank of the Aidaralash Creek, the left tributary of the Zhaksy-Kargaly River, about 10 km west of the Novorossiiskii Settlement, and 60 km east of the city of Aktyubinsk. The section was examined many times and described in literature (Ruzhentsev, 1950, 1952; Pnev *et al.*, 1978; Davydov and Popov, 1986; Davydov *et al.*, 1990). There are continuously and sequently exposed marine monofacies deposits of the Orenburgian to Sakmarian stages. The deposits are represented by alternating siltstones, mudstones, inequigranular polymictic calcareous sandstones, and sandy limestones. The alternation pattern and composition of rocks is persistent throughout the section; there is a unique combination of three orthostratigraphic faunal groups, which usually occur in alternative facies environments, namely ammonoids, fusulinids, and conodonts. Ammonoids seem to have been buried during their lifetime. Conodonts here are of mixed taxonomy. Their primary associations often coexist with older elements, even the Devonian ones. This may be attributed to the fact that the detritial sediments received materials of older rocks with conodonts. The Aidaralash fusulinids are of allochthonous origin. They were brought here from the adjacent shoals (the last whorls in most shells are filled with host sandy-clay material). Despite their allochthonous burial, the fusulinids' distribution in the Aidaralash section corresponds to the regularities observed in the normal sedimentary carbonate sections in other regions, namely in the Donets Basin, the Caspian depression, Central Asia (Leven and Shcherbovich, 1978; Shcherbovich, 1969; Popov *et al.*, 1987, 1989; Davydov, 1984, 1990). It is noteworthy that in terms of their biogeography, the fusulinid assemblages of the South Urals belong to the Tethyan province, though arctic elements are sufficiently well represented among the most widely spread species here.

Fusulinids in this section were discovered at 72 levels, ammonoids, at 33 levels, are conodonts, at 60 levels. The section is evenly saturated with these well preserved fossils, which facilitated an accurate definition of zonal boundaries according to successions in the assemblages. It is also possible to reconstruct the main phylogenetic lineages in fusulinids and ammonoids here, as well as the phylomorphologic series in conodonts. Partially, this possibility has already been realized. Faunal remains prove to be especially frequent in the transition from the Carboniferous to the Permian. Based upon the analyzed vertical distribution of ammonoids (Bogoslovskaya and Popov, 1986), fusulinids, and conodonts (Davydov and Popov, 1986; Davydov *et al.*, 1991), zones and subzones were identified and characterized in this section. All authors of this paper recognize these zones and subzones and accept them (Fig. 1). Palynological spectra were found throughout the entire section (Pnev *et al.*, 1978), and its paleomagnetic parameters were examined (Khramov and Davydov, 1991). The Aidaralash section is also a stratotype of the boundary *Ultradaixina bosbytauensis–Schwagerina robusta* and *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* (s. str.) fusulinid zones (*Resheniya ...*, 1984). The section meets all the requirements for stratotypes accepted in international practice (Cowie, 1986). For all these reasons, it is logical to suggest the Aidaralash section as a global stratotype for the Carboniferous–Permian boundary. The boundary was defined by the succession of ammonoid species in the *Artinskia irinae–A. kazakhstanica* phylogenetic lineage between strata 19/5 and 20 (the strata are numerated according to Davydov *et al.*,1991, Fig. 1). In the fusulinid scale, this level corresponds to the boundary between the *Ultradaixina bosbytauensis–Schwagerina robusta* and *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* (s. str.) zones (strata 19/5 and 19/6).

The exact relations between the chosen boundary and the conodont scale are still unclear. The identification and analysis of the Aidaralash conodont assemblages were conducted by L.Z. Akhmetshina, I.S. Barskov, R.I. Kozitskaya, and V.V. Chernykh. At present, the exact correlation of the lower boundary of the first Permian *Svetlanoceras–Juresanites* ammonoid zone and the boundaries of conodont zones in any versions of the conodont scales offered so far (Barskov, 1984; Movshovich *et al.*, 1979; Ovnatanova and Akhmetshina, 1987;



Stage	GZHELIAN		ASSELIAN	
Genozones by ammonoids	*Shumardites–Vidrioceras*		*Sveltianoceras–Juresanites*	
Zones by fusulinids	*Ultradaixina bosbytauensis–Schwagerina robusta*		*Sphaeroschwagerina vulgaris–S. fusiformis*	*S. moelleri–Schwagerina fecunda*
Subzones by fusulinids	*Ultradaixina postsokensis*	*Ultradaixina postgallowayi*	*S. vulgaris*	*S. fusiformis*	*Ps. salbulakens.*	*Ps. robusta*
Lithological beds	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29			

Fig. 1. Distribution of the main fossil species from the Carboniferous–Permian boundary deposits in the Aidaralash section.

Lithology: 1 – limestone, 2 – siltstone, claystone, 3 – clayey and sandy limestone, 4 – submarine–rock-slide mixtite, and 5 – gravelstone, conglomerate.

Fossils: 6 – fusulinids and 7 – ammonoids.

Species: 8 – nominative, 9 – with the "cf." sign, 10 – with the "aff." sign, 11 – with the "ex gr." sign.

FOSSIL SPECIES.

Ammonoids: 1 – *Glaphyrites pararhymnus* Ruzh., 2 – *Prothalassoceras jaikense* Ruzh., 3 – *Eoasianites vodorezovi* Ruzh., 4 – *Marathonites* sp., 5 – *Uddenites tuberculatus* Ruzh., 6 – *Prothalassoceras inflatum* Ruzh., 7 – *Aristoceras appressum* Ruzh., 8 – *Aristoceras serum* Bog. et A. Pop., 9 – *Almites reverendus* Bog. et A. Pop., 10 – *Daixites meglitzkyi* Ruzh., 11 – *Prouddenites terminalis* Ruzh., 12 – *Uddenites convexus* Ruzh., 13 – *Artinskia irinae* Ruzh., 14 – *Boesites aktubensis* bog. et A. Pop., 15 – *Daixites antipovi* Ruzh., 16 – *Artinskia kazakhstanica* Ruzh., 17 – *Svetlanoceras primore* Bog. et A. Pop., 18 – *Prostacheoceras principale* Bog. et A. Pop., 19 – *Prothalassoceras serratum* Max., 20 – *Glaphyrites angustilobatus* Ruzh., 21 – *Prothalassoceras biforme* Gerass., 22 – *Daixites attenuatus* Ruzh., 23 – *Eoasianites trapezoidailis* Max., 24 – *Artinskia nalivkini* Ruzh., and 25 – *Prostacheoceras juresanense* Max.

Fusulinids: 26 – *Occidentoschwagerina kizilkiensis* Dav., 27 – *Ocellina kljasmica* (Sjom.), 28 – *Ocellina buzulukensis* (Dobr.), 29 – *Ultradaixina postsokensis* Dav., 30 – *Ultradaixina bosbytauensis* Bensh, 31 – *Schwagerina ossinovkensis* (Scherb.), 32 – *Occidentoschwagerina alpina* (Kahl. et Kahl.), 33 – *O. chatcalica* Bensh, 34 – *Licharevites thompsoni* (Grozd.), 35 – *Rugosochusenella pseudogregaria* (Bensh), 36 – *Dutkevitchia tachigrada* (Bensh), 37 – *D. kargalensis* (Raus.), 38 – *Schwagerina vozhgalensis* (Raus.), 39 – *S. biconica* (Scherb.), 40 – *Ultradaixina postgallowayi* Bensh, 41 – *Schwagerina robusta* (Raus.), 42 – *Dutkevitchia ruzhenzevi* (Raus.), 43 – *Licharevites fornicatus* (Kanm.), 44 – *Ultradaixina dashtidzhumica* Dav., 45 – *Rugosochusenella paragregaria* (Raus.), 46 – *Dutkevitchia complicata* (Schellw.), 47 – *Licharevites nitidus* (Kahl. et Kahl.), 48 – *L. sartauensis* Dav., 49 – *L. inglorius* (Bensh), 50 – *Sphaeroschwagerina salomatiensis* (Ket.), 51 – *Licharevites esetensis* Dav., 52 – *Sphaeroschwagerina buzulukensis* (Dobr.), 53 – *S. shamovi primitiva* (Lev. et Scherb.), 54 – *S. vulgaris darvasica* (Lev. et Scherb.), 55 – *S. aktjubensis* (Scherb.), 56 – *S. volongica* (Scherb.), 57 – *S. kolvica* (Scherb.), 58 – *S. shamovi shamovi* (Scherb.), 59 – *Schwagerina versabile* (Bensh), 60 – *Licharevites gareckui* (Scherb.), 61 – *Paraschwagerina distincta* Lev. et Scherb., 62 – *Dutkevitchia devexa* (Raus.), 63 – *Schwagerina subnathorsthy* (Lee), 64 – *Paraschwagerina akhunovi* (Raus.), 65 – *Sphaeroschwagerina fusiformis* (Krotow), 66 – *S.* aff. *moelleri* (Raus.), 67 – *Pseudoschwagerina inexplorata* Lev. et Scherb., 68 – *Zigarella* aff. *pseudopointeli* (Raus.), 69 – *Sphaeroschwagerina postvulgaris* (Bensh), 70 – *Pseudoschwagerina robusta* (Meek), 71 – *P. uddeni* (Beede et Kniker), 72 – *Sphaeroschwagerina kargalensis* (Scherb.), 73 – *S. asiatica* (M. Maclay).

Conodonts: 74 – *Streptognathodus elongatus* Gunn., 75 – *S. simplex* Gunn., 76 – *S. alius* Akhmet., 77 – *S. wabaunsensis* Gunn., 78 – *S. insignitus* Akhmet., 79 – *S. nodulinearis* Chern. et Resh., 80 – *S. acuminatus* Gunn., 81 – *S. flangulatus* Gunn., 82 – *S. asselicus* Isak., 83 – *S. cristellaris* Chern. et Resh., 84 – *S. constrictus* Chern. et Resh., 85 – *S. barskovi* Kozur, 86 – *S.* ex gr. *fusus* Chern. et Resh.

Chernykh and Reshetkova, 1987, 1988; Chernykh and Chuvashov, 1991) does not seem possible for at least two reasons. First, there are some taxonomic problems that are still unsolved due to the ambiguous identification of key species from the genus *Streptognathodus*, which has been treated differently by various authors. Second, when establishing the zones, the authors disagreed in their approaches to the content and boundaries of the fusulinid scale. In addition, the materials varied in their representation quality.

For example, the index species of the *Streptognathodus wabaunsensis* Zone, whose base was suggested as the Carboniferous–Permian boundary (Barskov, 1984; Chernykh and Chuvashov, 1991), was found in the Aidaralash section much below the latter defined by ammonoids, still found in the *Daixina sokensis* fusulinid zone, which was *a priori* known to be the Carboniferous. The first appearance of *Streptognathodus cristellaris*, the index species of the basal Permian conodont zone, according to Chernykh and Reshetkova (1987, 1988), and also to Akhmetshina (1990), is recorded in the Aidaralash section in the lower third part of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* fusulinid zone (stratum 21), i.e., above the ammonoid level of the boundary. Still above it, in stratum 22, but also within the mentioned fusulinid zone, *S. barskovi* and *S. constrictus* occur.

At the same time, the level, practically coinciding with the appearance of the Asselian ammonoids and first *Sphaeroschwagerina*, reveals some species unmarked below, in the deposits *a priori* known to be the Carboniferous. However, up to now, these species were never used for formal identification of conodont boundaries. Right at the boundary fixed by ammonoids and fusulinids, in the upper part of stratum 19 and in stratum 20, *Streptognathodus acuminatus* (sensu Chernykh), *S. flangulatus,* and *S. asselicus* appear; slightly higher, in strata 21 and 22, *S. barskovi, S. cristellaris*, and *S. constrictus* occur.

Thus, the presence of any of the six species mentioned above may indicate the beginning of the Permian. To define formally the boundary of the first conodont zone with reliable accuracy, we must solve the taxonomic and methodological problems discussed above. In addition, it is also important to know the actual phylogeneses of this group of species representing the *Streptognathodus* genus. Today, the main evolutionary trends seem to be sufficiently definite in the following lineages: *Streptognathodus alius* → *S. barskovi* → *S. fusus*; *S. elongatus* → *S. acuminatus* (sensu Chernykh); *S. elongatus* → *S. cristellaris*; *S. wabaunsensis* → *S. flangulatus*. Detailed substantiation of these phylogenetic lineages in individual sections and choosing one of the lineages for formal identification of the Carboniferous–Permian boundary is an objective for future studies. For the time being, it is clear that this boundary occurs approximately between the first and the second members in each of the above phylogenetic lineages.

The established Carboniferous–Permian boundary, which is substantiated by fusulinids, conodonts, and ammonoids and reliably correlated with the magnetostratigraphic scale, can be traced through the sections in the Donets Basin in the standard scale of West European continental deposits. By means of fusulinids, the boundary can be also tied to units identified by other groups of benthonic organisms.

CORRELATION BY DIFFERENT FOSSIL GROUPS

Fusulinids

The East European platform. The Carboniferous–Permian boundary beds here are represented by secondary dolomitized limestones with fusulinids that are either absolutely destroyed or poorly preserved. For these reasons, practical definition of the boundary is rather difficult to accomplish. However, in some thoroughly studied sections this boundary can be defined with high accuracy.

For instance, according to Semina (1961), in the Moshachikha ravine (the region of the Klyaz'ma River), the Oka–Tsna uplift, the beds with *Ocellina bina* (Sjom.), *O. kljasmica* (Sjom.), *Schwagerina fortis* (Sjom.), *S. pomposa* (Sjom.), and other fusulinids from the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone are overlain by strata with poorly preserved *Sphaeroschwagerina* sp. A similar situation was observed in the section of well 11 on the Arzamas area in the Gorkii Region. Semina (Kireeva *et al.*, 1971) described an assemblage here with *Schwagerina pseudokrotowi* (Sjom.), *Ocellina bina* (Sjom.), *Schellwienia porrecta* (Sjom.), characterizing the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone, which is succeeded by a complex with *Sphaeroschwagerina* sp. and *Schwagerina rhomboides* (Sham. et Scherb.) of the *Sphaeroschwagerina vulgaris –Sphaeroschwagerina fusiformis* Zone.

During the last years, the Carboniferous–Permian boundary beds were additionally studied in the Samara Luka area (Murav'iev *et al.*, 1983; *Atlas Fauny* ..., 1986). An excursion was undertaken for experts in June, 1980, providing many of them with the opportunity to collect materials from the transitional Carboniferous–Permian strata. One of the authors of this paper (Davydov) found in his material the following fusulinid succession from the key section "Yablonovii Ovrag" in the Samara Luka area (the strata are numerated according to Murav'iev *et al.*, 1983):

(a) strata 27 - 35 – *Daixina sokensis, D. vasylkovskyi*, and other species characteristic of the *Daixina sokensis* Zone;

(b) strata 36 - 37 – *Ultradaixina* aff. *bosbytauensis, Schwagerina insignis* (Jagof.), *S. robusta* Raus., and *Ocellina orenburgensis* (Ket.), which unambigously correlate these strata to the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone;

(c) stratum 39 – *Sphaeroschwagerina vulgaris aktjubensis* (Scherb.), *S. borealis* (Scherb.), *S. fusiformis*

(Raus.), *S. kolvica* (Scherb.), *S.* ex gr. *moelleri* (Raus.), *Ocellina cara* (Dobr.), *O. kolpica* (Sjom.), *Schellwienia bornemani* (Lev. et Scherb.), and *Zigarella* aff. *asheinensis* (Sjom.). In the Middle and South Urals this complex characterizes the upper part of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone (the *Sphaeroschwagerina fusiformis* Subzone). Most likely, stratum 38 corresponds to the lower part of this zone.

According to Konovalova (1991), the Carboniferous–Permian boundary deposits in the Timan–Pechora region are subdivided in detail. There, above the beds with *Daixina sokensis uchtaensis* Kon., which are referred to the *Daixina sokensis* Zone, the following strata occur: (a) with *Schwagerina robusta*; (b) with *Ocellina pusilla* and first *Sphaeroschwagerina* sp.; c) with *Sphaeroschwagerina vulgaris* and *Rugosofusulina stabilis*. The stratum (a) exactly correlates with the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone, while the strata (b) and (c) belong to the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone.

According to Mikhailova (1974), on the Chernyshev Ridge, above the limestones with an assemblage of the *Daixina sokensis* Zone (*Daixina sokensis* Raus., *D. scherbovichae* Z. Mikh., *D. magna* Ros., and others), there are limestones with an assemblage of *Sphaeroschwagerina vulgaris* (Scherb.) and *S. timanica* (Scherb.). In the lower part of these limestones (according to a review of Mikhailova's collection) the layers with *Daixina tchernovi* Z. Mikh., *Zigarella* ex gr. *anderssoni* (Schellw.), and *Rugosochusenella paragregaria* (Raus.) and barren of *Sphaeroschwagerina* can be defined. Most likely, these beds correspond to the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. The overlying strata contain very primitive *Sphaeroschwagerina* forms which can be compared with those from the basal beds (strata 20 - 21) of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone from the Aidaralash sequence. The Carboniferous–Permian boundary is traced at the base of these strata.

In the Mezen' depression (Alekseeva, 1977), the *Daixina sokensis* Zone is established by the presence of index species and of some other *Daixina* species close to the latter. The overlying deposits referred to the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone are divided into two parts. The lower part contains species from the underlying beds accompanied by *Schwagerina robusta*, and endemic *Zigarella* species (*Z. mezensis* Aleks. and *Z. onerosa* Aleks.). In the upper part, *Schwagerina cybea* (Sjom.), *Zigarella paraanderssoni* (Rauser), *Likharevites astus* (Grozd.), and *L. nadezhdae* (Grozd.) predominate. The lower part of this unit undoubtedly corresponds to the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone; the upper part is conventionally, by its position in the section, referred to the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone. No *Sphaeroschwagerina* representatives occur in this part of the section.

The Urals. In the Urals, the *Daixina sokensis*, *Ultradaixina bosbytauensis–Schwagerina robusta*, and *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* zones (s. str.) are identified in practically all of the thoroughly studied sections. Some of them are known to have stratotypes of the above fusulinid zones. In the South Urals, in addition to the Aidaralash section, these zones were also identified in the Nikolol'skoye and Il'inskoye sections, as well as in the ditches of the Orsk–Orenburg railroad (Davydov and Popov, 1986).

It is also possible to define zonal units in the Carboniferous–Permian boundary deposits of Bashkiria (Chuvashov, 1986). However, since such data were collected from composite sections, they are not quite suitable for our purposes.

In the Middle Urals, boundary deposits are most completely represented and most thoroughly examined in the section of Kholodny Log locality (Ekhlakov and Zolotova, 1986), having a continuous sequence of limestones with abundant, diverse, and well preserved fauna. Layers 6 - 8 in exposure 26 revealed *Daixina sokensis* (Raus.), *D. recava* Zol., *D. tymanensis atypica* Zol., *Zigarella asherinensis* (Sjom.), *Z. fusina* (Scherb.), and others which correlates them with the *Daixina sokensis* Zone. Layers 0 - 3b in exposure 24 contain various species from the *Schwagerina robusta* group (Raus.), *S. vozhgalensis* (Raus.) and first *Occidentoschwagerina* and *Rugosochusenella*, which indicates the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. In layers 4 and 5 of exposure 24, in addition to the above species, first *Sphaeroschwagerina* ex gr. *vulgaris* (Scherb.) occur. Slightly higher, in layers 0 - 6 of exposure 22, *Sphaeroschwagerina* representatives become most numerous and most diverse: *S. kolvica* (Scherb.), *S. belajaensis* (Grozd.), *S. fusiformis* (Krot.), and others. These layers already belong to the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone. Layers 7 - 9 of exposure 22 show first *Sphaeroschwagerina shamovi gerontica* (Scherb.), *Schwagerina rhombiformis* (Sham. et Scherb.), *S. subnathorsthi* (Lee), *S. nux* (Schellw.), and others characterizing the *Sphaeroschwagerina moelleri–Schwagerina fecunda* Zone. The parastratotypes of the *Ultradaixina bosbytauensis–Schwagerina robusta* and *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* zones were established in the Kholodny Log section. Here, the level of the Carboniferous–Permian boundary can be very accurately identified by fusulinids between layers 3 and 4 of exposure 24 (Ekhlakov and Zolotova, 1986).

This boundary can also be accurately identified in the thoroughly studied sections on the Berezovaya River near the Vizhai Settlement, the North Urals (the Kamen' Stolby section), and also on the Kos'va River (the Ostanets section) (Ekhlakov and Zolotova, 1986; Shcherbakova, 1986).

The Cis-Donets Trough. The boundary deposits of this region are correlated by the results of the latest

studies (Davydov, 1990, 1992). The Skosyrskaya reference well (no. 4199), at a depth of 577 - 579 m, drilled a limestone identified as P_5 (*Opornyi Razrez ...*, 1983) with sufficiently diverse *Occidentoschwagerina*, indicating the base of the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. At a depth of 393 - 394 m, in the limestone of Q_9, *Ultradaixina bosbytauensis* Bensh, *U. postgallowayi* Bensh, and *Likharevites fornicatus* (Kanm.) are found, all pointing to the upper half of the above zone. At a depth of 385 m, at the base of the Skosyrskaya Formation, first *Likharevites esetensis* Dav., and *L. sartauensis* Dav. were discovered among fusulinids. These species in the South Urals occur together with first *Sphaeroschwagerina*, thus indicating the Carboniferous–Permian boundary. Ten meters above the base of the Skosyrskaya Formation, *Sphaeroschwagerina fusiformis* (Krotov) are recorded, which already characterize the upper half of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone. Thus, the Carboniferous–Permian boundary lies between the limestone Q_9 and the base of the Skosyrskaya Formation (Leven, 1986; Davydov, 1990, 1992).

Central Asia. In Central Asia the most complete and most thoroughly examined sections of Carboniferous-Permian boundary deposits are located in the Darvaz and Karachatyr area. In the Darvaz area the boundary beds in the Safetgyr section are subdivided in detail (Davydov, 1984; Leven and Davydov, 1986). Beds 150 - 169 reveal *Daixina sokensis* Raus., *D. vasylkovsky* Bensh, *Schellwienia modesta* (Scherb.), and *Zigarella elegans* (Bensh), which reliably correlate the deposits with the *Daixina sokensis* Zone. These beds are overlain by deposits with *Ultradaixina bosbytauensis* Bensh, *U. postsokensis* Dav., *Occidentoschwagerina alpina* (Kahl. et Kahl.), numerous *Ocellina*, *Rugosochusenella*, and *Schwagerina* (beds 170 - 187). Still higher up (beds 188 - 219) *Ultradaixina postgallowayi* (Bensh), *Likharevites fornicatus* (Kanm.), and *Schwagerina robusta* (Raus.) occur. These deposits in the section were first identified as the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone (Leven and Davydov, 1979). The overlying limestones (beds 220 - 240) contain fusulinids, known from the underlying strata too, and first *Sphaeroschwagerina* represented by most primitive species, such as *S. vulgaris aktjubensis* (Scherb.), *S. vulgaris ashensis* (Scherb.), and *S. vulgaris darvasica* (Lev. et Scherb.). The Darvaz sections prove to be among the best within the interval from the Moskovian to the beginning of the Sakmarian Stage; the succession of Tethyan fusulinids is most complete here (Leven and Shcherbovich, 1978; Davydov, 1984; Leven and Davydov, 1986, 1991).

In Karachatyr, after reexamination of the type sections of the regional Upper Carboniferous and Lower Permian scale (Davydov, 1987; Popov *et al.*, 1987, 1989), it was found that the succession of fusulinid assemblages and their characteristics are in many ways identical with those from the Darvaz sections. The beds with *Daixina sokensis* Raus., *D. recava* Zol., *D. vasylkovskyi* Bensh, *Dutkevitchia dastarensis* (Bensh), and *Ruzhenzevites ferganensis* (Dutk.) (beds 25 - 38) correlative with the *Daixina sokensis* Zone are overlain by beds 27/1-3 with *Ultradaixina bosbytaueunsis* (Bensh), *U. postsokensis* Dav., and *Occidentoschwagerina alpina* (Kahl. et Kahl.), which already belong to the lower part of the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. The upper half of this zone (bed 27/5-7) is characterized by *Ultradaixina postgallowayi* (Bensh), *Occidentoschwagerina kokpectensis* Scherb., *Likharevites fornicatus* (Kanm.), and *L. paranitidus* (Bensh). Still higher, in beds 27/8-14, along with dominant *Ruzhenzevites ferganensis* (Dutk.), *F. parasolodus* (Bensh), and *Pseudofusulinoides subobscurus* Bensh also rare *Likharevites esetensis* Dav. and *Schwagerina versabila* (Bensh), occur which in Darvaz and in the South Urals, characterize the lower half of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone. Such a correlation of the above beds is supported by the fact that the overlying strata (27/16) contain *Sphaeroschwagerina fusiformis* (Krotov), *S.* aff. *shamovi* (Scherb.), and *S.* ex gr. *mukhamedjarovi* (Scherb.) typical of the upper half of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone.

The Arctic region. Today, the most thoroughly studied and most complete among the Arctic sections are those in the Timan–Pechora area and in Spitsbergen. In the Timan–Pechora area, the *Daixina sokensis* Zone is subdivided into beds with *Daixina sokensis uchtaensis* and *Daixina enormis* (Konovalova, 1991). The latter contain species typical of the *Daixina sokensis* Zone (*Daixina vasylkovskyi* Bensh, *D. recava* Zol., and *D. zsui* Vol.), and also *Schwagerina gracilis* Sjom. It shows that at least some of these strata already belong to the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. Konovalova includes the overlying beds into the lower zone of the Asselian Stage. She identifies two subzones there: (a) *Schwagerina robusta*, *Ocellina kljasmica*, and (b) *Sphaeroschwagerina fusiformis*, *S. vulgaris*. The lower subzone, in turn, is subdivided into beds with *Schwagerina robusta*, undoubtedly belonging to the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone, and beds with *Ocellina kljasmica*. The latter reveal first rare *Sphaeroschwagerina* sp., which indicates that they belong to the lower part of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone. The upper part of this zone corresponds to the *Sphaeroschwagerina fusiformis–Sphaeroschwagerina vulgaris* Subzone from the Timan–Pechora area (Konovalova, 1991). Thus, the Carboniferous–Permian boundary may be very precisely established here between the beds with *Schwagerina robusta* and those with *Ocellina kljasmica*.

In recent years, detailed studies were carried out on Spitsbergen (Nilsson, 1988; Nilsson and Davydov, 1993). They also allowed us to trace the Carboniferous–Permian boundary very accurately. Here, the Carboniferous–Permian boundary deposits revealed the following succession. Limestones with *Daixina sokensis uchtaensis* Kon., *D. recava* Zol., *Schellwienia*

arctica (Schellw.), *S. krushiensis* (Alksne), *S. malkovskyi* (Ket.), and *Zigarella praegregaria* (Scherb.) referred to the *Daixina sokensis* Zone are overlain by strata with *Schwagerina robusta* (Raus.), *S. insignis* (Jag.), *S. acris* (Sjom.), *S. gracilis* (Sjom.), *Schellwienia visotchnajaensis* (Kon.), *S. plena* (Kon.), and *Zigarella simplex* (Kon.) identified as the *Schwagerina robusta* Zone. They reliably correlate with the standard *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. Still higher, there are limestones with *Zigarella pseudoanderssoni* (Sjom.), *Z. narjanmarica* (Kon.), *Z. anderssoni* (Schellw.), *Z. furnishi* (Ross.), rare *Occidentoschwagerina fusulinoides* (Schellw.), *O. ancestralis* (Echlak.), *Licharevites* cf. *sartauensis* Dav., and *Sphaeroschwagerina* ex gr. *fusiformis* (Krotow), which are identified as the *Zigarella anderssoni* Zone. This zone can be satisfactorily correlated with the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone of the standard fusulinid scale. Thus, the Carboniferous–Permian boundary in the Spitsbergen sections can be precisely drawn between the *Schwagerina robusta* and *Zigarella anderssoni* zones (Nilsson and Davydov, 1993).

China. Until now, Chinese experts differ in their opinion on the position of the Carboniferous–Permian boundary in China. Traditionally, it was defined there between the Maping and the Qixia formations (approximately at the base of the Yachtashian / = Artinskian / Stage, in other words, much higher than it is accepted everywhere else in the world). In the recent years, many Chinese stratigraphers have been inclined to lower this boundary to the base of the Maping Formation, where its position approximately coincides with the generally accepted one (Rui Lin *et al.*, 1989). However, to establish this level of the boundary in actual sections proves to be rather difficult due to the essential endemism of the Gzhelian–Early Asselian fusulinid assemblages predominated by representatives of *Triticites*. The species of *Daixina*, *Occidentoschwagerina*, *Likharevites*, *Sphaeroschwagerina*, and other genera used in other countries as indicators for the Carboniferous–Permian boundary China occur in this level relatively seldom, thus requiring careful searches to find them. In addition, tracing the Carboniferous–Permian boundary in China is difficult because of considerable divergences in the classification and taxonomy of fusulinids, particularly of the so-called "Schwagerina-like" species. One of the authors of this paper (Leven) had an opportunity to look through the materials collected layer-to-layer from the Houchang section in the province of Guizhou, South China. The section was presented during the International Congress on Carboniferous Stratigraphy and Geology, which was held in China in 1987. The section was presented as a reference for the Upper Carboniferous and Lower Permian. The monograph describing the Houchang section (Xiao *et al.*, 1986) relates the entire Maping Formation to the Upper Carboniferous. The formation includes the following zones: *Montiparus weiningica*, *Triticites*, "*Pseudoschwagerina uddeni*," and *Sphaeroschwagerina*. The first two zones undoubtedly belong to the Upper Carboniferous. The "*Pseudoschwagerina uddeni*" Zone is 11.6 m thick and is subdivided into several beds (from F-1 to F-8). Typical Ultradaixina bosbytauensis (Bensh) is found in bed F-4. This is a zonal species of the uppermost Gzhelian zone bearing the same name. Only 2 to 3 m upward the section, in bed F-7, a first occurrence of *Sphaeroschwagerina* ex gr. *vulgaris* (Scherb.) is recorded, which indicates the basal part of the Asselian Stage.

Thus, the above data show that by using the criteria elaborated for the Ural sections, the Carboniferous–Permian boundary can also be identified in South China's sections within an accuracy of several meters. It may seem rather strange that this boundary happens to lie inside the "*Pseudoschwagerina uddeni*" Zone, since the zonal species is among the most characteristic forms of the middle part of the Asselian Stage. However, the entire material on the Houchang section did not reveal a single form that could be related to this species. Most likely, the forms with montiparuslike juvenarium and with relatively freely coiled whorls of shells, which morphologically resemble *Pseudoschwagerina*, were referred to this species, though, in fact, they seem to belong to a new genus *Carboschwagerina*, which is characteristic of the Upper Carboniferous of Japan.

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In the Akiyoshi section, in the vicinities of the Akiyoshi-Dai Science Museum, the "*Schwagerina*?" *satoi* Zone, which seems to relate to the Upper Kasimovian or Lower Gzhelian deposits, is followed by the *Carboschwagerina morikawai* Zone. The index species of this zone is close to *Carboschwagerina gusanicus* (Bensh) from the Lower Gzhelian deposits in South Fergana (Bensh, 1972) and Darvaz (Davydov, 1984). Watanabe correlates this zone with the lower zone of the Gzhelian Stage. Located still upward in the section is the *Carboschwagerina minatoi* Zone, whose age may

studies (Davydov, 1990, 1992). The Skosyrskaya reference well (no. 4199), at a depth of 577 - 579 m, drilled a limestone identified as P_5 (*Opornyi Razrez ...*, 1983) with sufficiently diverse *Occidentoschwagerina*, indicating the base of the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. At a depth of 393 - 394 m, in the limestone of Q_9, *Ultradaixina bosbytauensis* Bensh, *U. postgallowayi* Bensh, and *Likharevites fornicatus* (Kanm.) are found, all pointing to the upper half of the above zone. At a depth of 385 m, at the base of the Skosyrskaya Formation, first *Likharevites esetensis* Dav., and *L. sartauensis* Dav. were discovered among fusulinids. These species in the South Urals occur together with first *Sphaeroschwagerina*, thus indicating the Carboniferous–Permian boundary. Ten meters above the base of the Skosyrskaya Formation, *Sphaeroschwagerina fusiformis* (Krotov) are recorded, which already characterize the upper half of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone. Thus, the Carboniferous–Permian boundary lies between the limestone Q_9 and the base of the Skosyrskaya Formation (Leven, 1986; Davydov, 1990, 1992).

Central Asia. In Central Asia the most complete and most thoroughly examined sections of Carboniferous-Permian boundary deposits are located in the Darvaz and Karachatyr area. In the Darvaz area the boundary beds in the Safetgyr section are subdivided in detail (Davydov, 1984; Leven and Davydov, 1986). Beds 150 - 169 reveal *Daixina sokensis* Raus., *D. vasylkovsky* Bensh, *Schellwienia modesta* (Scherb.), and *Zigarella elegans* (Bensh), which reliably correlate the deposits with the *Daixina sokensis* Zone. These beds are overlain by deposits with *Ultradaixina bosbytauensis* Bensh, *U. postsokensis* Dav., *Occidentoschwagerina alpina* (Kahl. et Kahl.), numerous *Ocellina*, *Rugosochusenella*, and *Schwagerina* (beds 170 - 187). Still higher up (beds 188 - 219) *Ultradaixina postgallowayi* (Bensh), *Likharevites fornicatus* (Kanm.), and *Schwagerina robusta* (Raus.) occur. These deposits in the section were first identified as the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone (Leven and Davydov, 1979). The overlying limestones (beds 220 - 240) contain fusulinids, known from the underlying strata too, and first *Sphaeroschwagerina* represented by most primitive species, such as *S. vulgaris aktjubensis* (Scherb.), *S. vulgaris ashensis* (Scherb.), and *S. vulgaris darvasica* (Lev. et Scherb.). The Darvaz sections prove to be among the best within the interval from the Moskovian to the beginning of the Sakmarian Stage; the succession of Tethyan fusulinids is most complete here (Leven and Shcherbovich, 1978; Davydov, 1984; Leven and Davydov, 1986, 1991).

In Karachatyr, after reexamination of the type sections of the regional Upper Carboniferous and Lower Permian scale (Davydov, 1987; Popov *et al.*, 1987, 1989), it was found that the succession of fusulinid assemblages and their characteristics are in many ways identical with those from the Darvaz sections. The beds with *Daixina sokensis* Raus., *D. recava* Zol., *D. vasylkovskyi* Bensh, *Dutkevitchia dastarensis* (Bensh), and *Ruzhenzevites ferganensis* (Dutk.) (beds 25 - 38) correlative with the *Daixina sokensis* Zone are overlain by beds 27/1-3 with *Ultradaixina bosbytaueunsis* (Bensh), *U. postsokensis* Dav., and *Occidentoschwagerina alpina* (Kahl. et Kahl.), which already belong to the lower part of the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. The upper half of this zone (bed 27/5-7) is characterized by *Ultradaixina postgallowayi* (Bensh), *Occidentoschwagerina kokpectensis* Scherb., *Likharevites fornicatus* (Kanm.), and *L. paranitidus* (Bensh). Still higher, in beds 27/8-14, along with dominant *Ruzhenzevites ferganensis* (Dutk.), *F. parasolodus* (Bensh), and *Pseudofusulinoides subobscurus* Bensh also rare *Likharevites esetensis* Dav. and *Schwagerina versabila* (Bensh), occur which in Darvaz and in the South Urals, characterize the lower half of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone. Such a correlation of the above beds is supported by the fact that the overlying strata (27/16) contain *Sphaeroschwagerina fusiformis* (Krotov), *S.* aff. *shamovi* (Scherb.), and *S.* ex gr. *mukhamedjarovi* (Scherb.) typical of the upper half of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone.

The Arctic region. Today, the most thoroughly studied and most complete among the Arctic sections are those in the Timan–Pechora area and in Spitsbergen. In the Timan–Pechora area, the *Daixina sokensis* Zone is subdivided into beds with *Daixina sokensis uchtaensis* and *Daixina enormis* (Konovalova, 1991). The latter contain species typical of the *Daixina sokensis* Zone (*Daixina vasylkovskyi* Bensh, *D. recava* Zol., and *D. zsui* Vol.), and also *Schwagerina gracilis* Sjom. It shows that at least some of these strata already belong to the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. Konovalova includes the overlying beds into the lower zone of the Asselian Stage. She identifies two subzones there: (a) *Schwagerina robusta*, *Ocellina kljasmica*, and (b) *Sphaeroschwagerina fusiformis, S. vulgaris*. The lower subzone, in turn, is subdivided into beds with *Schwagerina robusta*, undoubtedly belonging to the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone, and beds with *Ocellina kljasmica*. The latter reveal first rare *Sphaeroschwagerina* sp., which indicates that they belong to the lower part of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone. The upper part of this zone corresponds to the *Sphaeroschwagerina fusiformis–Sphaeroschwagerina vulgaris* Subzone from the Timan–Pechora area (Konovalova, 1991). Thus, the Carboniferous–Permian boundary may be very precisely established here between the beds with *Schwagerina robusta* and those with *Ocellina kljasmica*.

In recent years, detailed studies were carried out on Spitsbergen (Nilsson, 1988; Nilsson and Davydov, 1993). They also allowed us to trace the Carboniferous–Permian boundary very accurately. Here, the Carboniferous–Permian boundary deposits revealed the following succession. Limestones with *Daixina sokensis uchtaensis* Kon., *D. recava* Zol., *Schellwienia*

arctica (Schellw.), *S. krushiensis* (Alksne), *S. malkovskyi* (Ket.), and *Zigarella praegregaria* (Scherb.) referred to the *Daixina sokensis* Zone are overlain by strata with *Schwagerina robusta* (Raus.), *S. insignis* (Jag.), *S. acris* (Sjom.), *S. gracilis* (Sjom.), *Schellwienia visotchnajaensis* (Kon.), *S. plena* (Kon.), and *Zigarella simplex* (Kon.) identified as the *Schwagerina robusta* Zone. They reliably correlate with the standard *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. Still higher, there are limestones with *Zigarella pseudoanderssoni* (Sjom.), *Z. narjanmarica* (Kon.), *Z. anderssoni* (Schellw.), *Z. furnishi* (Ross.), rare *Occidentoschwagerina fusulinoides* (Schellw.), *O. ancestralis* (Echlak.), *Licharevites* cf. *sartauensis* Dav., and *Sphaeroschwagerina* ex gr. *fusiformis* (Krotow), which are identified as the *Zigarella anderssoni* Zone. This zone can be satisfactorily correlated with the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* Zone of the standard fusulinid scale. Thus, the Carboniferous–Permian boundary in the Spitsbergen sections can be precisely drawn between the *Schwagerina robusta* and *Zigarella anderssoni* zones (Nilsson and Davydov, 1993).

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be only approximated as Late Gzhelian because its assemblage has no characteristic fusulinids, which could indicate the zonal age in accordance with the standard scale for the Russian platform and the Urals. Watanabe (1991) correlates the *Carboschwagerina minatoi* Zone with *Jigulites jigulensis* and *Daixina sokensis* zones of the East European platform standard scale. Such an approach may be acceptable. The Upper Carboniferous deposits are overlain by beds belonging to the *Sphaeroschwagerina fusiformis* Zone. In the Akiyoshi-Dai Science Museum section, the fusulinid assemblage of this zone is characterized by representatives of *Ocellina*, *Rugosochusenella*, and *Sphaeroschwagerina*. In terms of their development, these forms are extremely primitive and most likely indicative of the Lower Asselian. Hence, we may say that the Carboniferous–Permian boundary here occurs at the base of the above zone.

A similar succession of zonal assemblages is established in the sections of the Atetsu and Omi localities (Watanabe, 1991), where the Carboniferous–Permian boundary lies at the base of the *Sphaeroschwagerina fusiformis* Zone. It is still unclear if these sections, and Japan in general, have any analogs of the *Ultradaixina bosbytauensis–Schwagerina robusta* Zone. According to Watanabe's materials (1991), it is difficult to answer this question clearly. However, the fact that *Ultradaixina katoi* (Choi, 1973), which is close to *Ultradaixina postgallowayi* (Bensh), was discovered in the Kitakami Mountains (Japan) is evidence that these deposits may also occur in Japan.

North America. In North America, accurately tracing the boundary as established by fusulinids is even more difficult for some basic reasons. The benthic nature and lateral variation of American fusulinid assemblages makes them so peculiar that direct tracing of the Carboniferous–Permian boundary using *Sphaeroschwagerina* is simply impossible. However, the well-studied general regularities of fusulinid evolution permit us to distinguish their Carboniferous assemblages from Permian ones with more or less reliable accuracy (Ross, 1980; Wilde, 1984, 1990). In the well known and more complete North American sections, this boundary seems to lie at the top of the Wabaunsee Group deposits of eastern Kansas, the Grey Limestone Member of the Glass Mountains, the Harquilla Limestone of southeast Arizona, the Cisco Formation of central Texas, and the Wild Cow Formation in New Mexico (Myers, 1988; Ross, 1980) (Fig. 2). To provide a more precise and more exact definition of this boundary according to fusulinids, special complex studies must be conducted in North America.

SMALLER FORAMINIFERS

Smaller foraminifers in Carboniferous–Permian boundary beds were examined very poorly. However, this is one of the few faunal groups that makes it possible to correlate type sections with those from Siberia and the Verkhnyaya Yana regions. The distribution of small foraminifers in boundary layers was studied in the Darvaz sections (Davydov, 1986b), the subdivision and correlation of which is well substantiated by fusulinids (Leven and Shcherbovich, 1978; Davydov, 1984). In the Boreal area, this boundary can be preliminarily fixed by the appearance of *Nodosaria* with deep convoluate, intricately attached chambers, and also of first *Geinitzina* (Leven and Sosipatrova, 1984; Davydov, 1986).

Ammonoids

According to ammonoids, the Carboniferous–Permian boundary can be traced less accurately than when based on fusulinids, but still sufficiently reliably, especially in such sections where their remains occur at several levels. Evolutionary regularities of Late Paleozoic ammonoids were studied sufficiently enough to permit us, without great difficulties, to distinguish the Late Carboniferous forms from the Permian ones. The trends in morphology changes found in the evolution of many families and genera allow precise identification the taxon position in the phylogenetic lineage and hence the age of the deposits enclosing it. For example, in northeastern Russia, the oldest Permian ammonoids are *Juresanites menneri* (Andr.) and *Eoasianites maximovae* (Andr.). Both of these species were discovered in the lower beds of the Tuorasis Formation in the northern Verkhnyaya Yana area, which is the stratotype area of this formation (Andrianov, 1985). *Juresanites menneri* seems to be the oldest species of this genus that was an ancestor in the Metalegoceratidae family. The latter was one of the four families whose origin initiated the Permian phase in the evolution of Late Paleozoic ammonoids. The development of its septum (the umbonal lobe shows the earliest stage of its trinominal division) identifies *J. menneri* as very close to the *J. originalis* discovered in the lowermost Asselian beds of the Urals (Shkolin, 1993). Undoubtedly, both of these species preceed *J. primitivus*, which is spread throughout the South Urals, in the middle of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* fusulinid zone. They indicate the lowest beds of the Permian system. Such a conclusion does not contradict the fact that the same level revealed *Eoasianites maximovae* from the group with narrow-whorled *Eoasianites* of the *E. vodorezovi* Ruzh. type. The latter are characteristic of Late Carboniferous and Early Permian species of the South Urals and North America. As compared with similar narrow-whorled Late Carboniferous species of this genus, *E. maximovae* differs in its relatively highly organized lobe line showing the base of all of the lobes to be strongly delineated. The finds made in the higher beds of the Tuorasis Formation definitely display Asselian–Sakmarian species of *Bulunites*, *Neopronorites*, and *Tabantalites* genera. This discovery corresponds to the conclusion concerning the Early Asselian age of the lower part of the Tuorasis Formation (Andrianov, 1985).

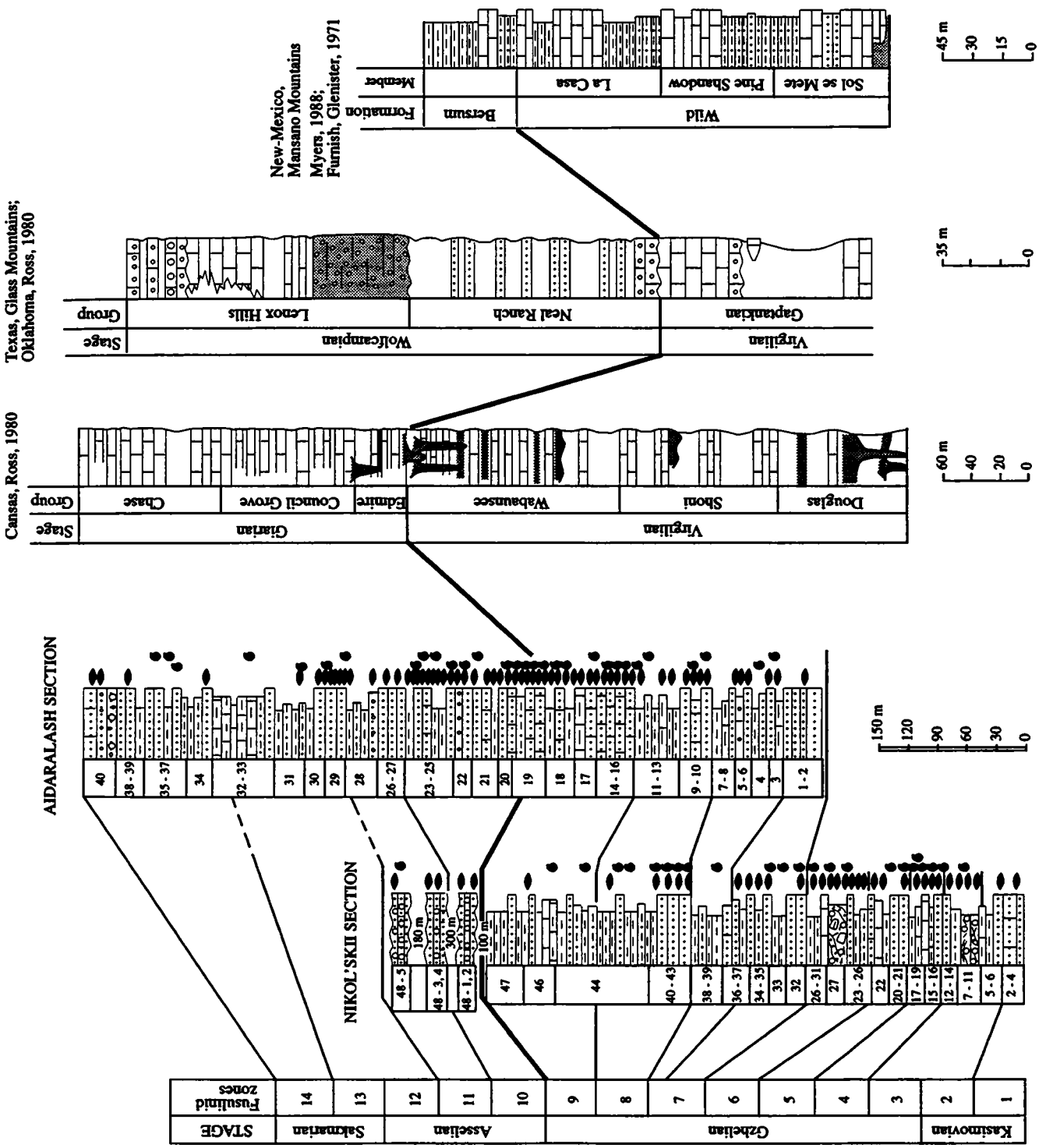

Fig. 2. Correlation of Carboniferous–Permian boundary deposits from the South Urals and the most important sections of North America. See the symbols in Fig. 1.

Zones and subzones according to fusulinids; 0 – *Protriticites pseudomontiparus–Obsoletes obsoletus*; 1 – *Montiparus montiparus*; 2 – *Rauserites quasiarcticus–R. acutus*; 3 – *Daixina fragilis*; 4 – *D. crispa*; 5 – *D. ruzhenzevi*; 6 – *D. enormis*; 7 – *D. vasylkovskyi*; 8 – *Ultradaixina postsokensis*; 9 – *U. postgalloway*i; 10 – *Sphaeroschwagerina vulgaris–S. fusiformis*; 11 – *Sphaeroschwagerina moelleri–Schwagerina fecunda*; 12 – *Sphaeroschwagerina sphaerica–Schwagerina firma*; 13 – *Sakmarella moelleri*; 14 – *Schwagerina uralica*.

In North America, as it is known, the Carboniferous–Permian boundary was established at the level of the Virgilian–Wolfcampian boundary in the base of the Neal Ranch Formation, the Glass Mountains, west Texas. It seems to be more correct to integrate this boundary with the upper boundary of the Pennsylvanian Gaptank Formation. A hiatus marked above the latter corresponds to the lower part of the Asselian Stage, at least within the limits of the *Sphaeroschwagerina vulgaris–Sphaeroschwagerina fusiformis* fusulinid Zone, or the *Artinskia kazakhstanica* ammonoid Zone in the South Urals (Davydov and Popov, 1986). This conclusion is supported by the analysis of numerous ammonoids from the Neal Ranch Formation. They revealed species that by their organizational level are close to the Late Asselian ones. Among such advanced species are the following: *Almites sellardsi* (P. et S.), *Prothalassoceras welleri* Bose, *Properrinites bakeri* (P. et S.), as well as representatives of the genus *Artinskia*, most likely erroneously identified with the Artinskian species *Artinskia artiensis* (Grun.) (Furnish and Glenister, 1971). This assemblage, as a whole, already belongs to the Lower Permian. Its age does not allow us to correlate the lower boundary of the Neal Ranch Formation with the Asselian lower boundary of the Aidaralash section. The former, without doubt, has a higher position and, most probably, passes near the upper boundary of the lower fusulinid zone.

The oldest ammonoids, which in their age are close to those from stratum 20 of the Aidaralash section, are known in New Mexico (the Bersum Formation in the vicinities of Tularosa) and in Oklahoma (the Red Eagle Limestones of the Council Grove Formation). The old age of these complexes is confirmed by the presence of the genus *Mescalites*, which undoubtedly descends directly from the Late Pennsylvanian genus *Goniolobоceras* (Furnish and Glenister, 1971). In the Bersum Formation, this genus is accompanied by Permian *Properrinites*, *Crimites*, Late Carboniferous–Permian *Almites*, and *Artinskia*, known from the North America Carboniferous. There are also numerous *Eoasianites* that are widespread in the Upper Pennsylvanian. In the Red Eagle Limestones of Oklahoma, *Mescalites* are accompanied by numerous narrow-coiled *Eoasianites*. It seems that the Carboniferous–Permian boundary, defined in North America by the appearance of *Mescalites*, is quite comparable with that in the South Urals.

Conodonts

The available data on conodonts from the boundary interval in other regions of the world are still scarce. Nevertheless, they can be used for some sufficiently reliable comparisons. According to the latest studies of Sobolev and Nakrem (1992), the *Streptognathodus wabaunsensis* Zone can be identified in the upper subformation of the Stepovo Formation and in the upper part of the Lazarev Formation on Novaya Zemlya Island. The *Streptognathodus cristelllaris* Zone was established in the basal part of the Talbeyakha Formation. The Carboniferous–Permian boundary is traced between these two zones.

In the Canadian Arctic region (Henderson, 1990), the Carboniferous–Permian boundary is established within the Nansen Formation at the level correlated with the base of the *"Pseudofusulina" plana* fusulinid Zone, where first *Streptognathodus wabaunsensis* and *S. nodulinearis* occur. The latter species was also found in the Aidaralash section of the South Urals. It also denotes the Asselian base, which allows us, so far, to share Henderson's opinion. It could be possible to establish the boundary more or less accurately by fusulinids but they are still unknown here. The species *"Pseudofusulina" plana* Skinner et Wilde, which is usually referred to by scientists to indicate the Carboniferous–Permian boundary in the Canadian Arctic region, is endemic and its generic affinity is not quite clear.

According to Ritter (1991), the American Midcontinental sections in Oklahoma and Kansas, namely the Limestones of Falls City and Red Eagle in the Council Grove Formation, reveal first *Streptognathodus wabaunsensis* and *S. flangulatus*, permitting us to correlate these limestones with the Permian base of the South Urals. The lower beds of the Neva Limestone display first *Sweetognathus* and *Streptognathodus* cf. *longissimus*. Ritter correlates this level with the base of the *Streptognathodus constrictus* Zone of the South Urals. The level of the Carboniferous–Permian boundary, as suggested by the authors of this paper, occurs within the Falls City and Red Eagle Limestones.

In China, in the Nashui section of southern Guizhou, the sequence of conodont zones (Wang Zhi-Hao, 1991) was found to be similar with that in the South Urals (Chernykh and Reshetkova, 1988). The upper beds of Upper Carboniferous comprise the *Streptognathodus elongatus* and *Streptognathodus wabaunsensis* zones. The Permian part of this section begins with the *Streptognathodus barskovi* Zone, which corresponds to our data.

Thus, the suggested boundary meets all the necessary requirements and may be used on a global scale. The boundary was selected in the region that was the first to reveal the Permian system and its basal, Asselian Stage. The base of. this stage was established by its author, Ruzhentsev, exactly at the level that we offer to fix as the Carboniferous–Permian boundary in order to preserve the historical priority. The established boundary is characterized by the three leading groups of fauna: ammonoids, conodonts, and fusulinids. Their assemblages simultaneously show changes at this very level. It is at this level that ammonoids, spread in the Carboniferous deposits, are quickly and distinctly succeeded by typically Permian ones. The fusilinids at this level reveal *Sphaeroschwagerina* of great geographical distribution, which are clearly identified by scientists. Also of decisive significance is the fact that the chosen stratotype of this boundary is represented by a section of unique parameters (the Aidaralash). Here, the

boundary is actually expressed in the continuous succession of all the leading faunal groups. The distribution of ammonoids, fusulinids, and conodonts in the Aidaralash section sufficiently displays their main evolutionary regularities and demonstrates the completeness of the section lacking hiatuses. This boundary has great correlational potential and can be globally traced by ammonoids, fusilinids, conodonts, and paleomagnetic data.

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REFERENCES

Akhmetshina, L.Z., Conodonts from Boundary Carboniferous–Permian Beds of the Eastern Margin of the Cis-Caspian Sea Trough, *Byull. MOIP, Otd. Geol.*, 1990, vol. 65, no. 1, pp. 80 - 88.

Alekseeva, I.A., Upper Carboniferous and Lower Permian Stratigraphy of Northwestern Timan Area (The Mezen' Trough) according to Fusulinids, *Cand. Sci. (Geology and Mineralogy) Dissertation*, Leningrad: VSEGEI (All-Union Geological Inst.), 1977.

Andrianov, V.N., *Permskie i Nekotorye Kamennougol'nye Ammonoidei Severo-Vostoka Azii* (Permian and Some Carboniferous Ammonoids of North-East Asia), Novosibirsk: Nauka, 1985.

Atlas Fauny Verkhnego Karbona i Nizhnei Permi Samarskoi Luki (Atlas of Upper Carboniferous and Lower Permian Fauna of the Samara Luka Area), Murav'iev, I.S. and Grigor'ieva, A.D., Eds., Kazan': Kazan. Univ., 1986.

Barskov, I.S., Zonal Scale of Upper Carboniferous and of Asselian Permian Stage according to Conodonts and Tasks of Its Updating, *Verkhnii Karbon SSSR* (Upper Carboniferous of the USSR), Moscow: Nauka, 1984, pp. 102 - 107.

Bensh, F.R., *Fusulinidovye Zony i Yarusnoe Raschlenenie Verkhnego Karbona i Nizhnei Permi Srednei Azii* (Fusulinid Zones and Stage Subdivision of Upper Carboniferous and Lower Permian in Central Asia), Tashkent: Fan, 1982.

Bensh, F.R., *Stratigrafiya i Fusulinidy Verkhnego Paleozoya Yuzhnoi Fergany* (Upper Paleozoic Stratigraphy and Fusulinids of Southern Fergana), Tashkent: Fan, 1972.

Bogoslovskaya, M.F. and Popov, A.V., Ammonoids at the Carboniferous–Permian Boundary, *Pogranichnye Otlozheniya Karbona i Permi Urala, Priural'ya i Srednei Azii* (Boundary Carboniferous–Permian Deposits of the Urals, Cis-Urals and Central Asia), Moscow: Nauka, 1986, pp. 56 - 63.

Chernykh, V.V. and Reshetkova, N.P., *Biostratigrafiya i Konodonty Pogranichnykh Otlozhenii Karbona i Permi Zapadnogo Sklona Yuzhnogo i Srednego Urala* (Biostratigraphy and Conodonts of the Carboniferous–Permian Boundary Deposits from the Western Slope of the South and Middle Urals), Preprint, Sverdlovsk: UNTs Akad. Nauk SSSR, 1987.

Chernykh, V.V. and Reshetkova, N.P., Zonal Conodont Division of Carboniferous–Permian Boundary Deposits from the Western Slope of the Middle and South Urals, *Biostratigrafiya i Litologiya Verkhnego Paleozoya Urala* (Upper Paleozoic Biostratigraphy and Lithology of the Urals), Sverdlovsk: UrO Akad. Nauk SSSR, 1991.

Choi, D.R., Permian Fusulinids from the Setamai–Yahagi District, Southern Kitakami Mountains, NE Japan, *J. Fac. Sci. Hokkaido Univ., Ser. IV*, 1973, vol. 15, nos. 3, 4, pp. 625 - 646.

Chuvashov, B.I., Carboniferous–Permian Boundary Deposits in Terrigenic Facies from the Middle Urals and Northern Western Slope of the South Urals, *Pogranichnye Otlozheniya Karbona i Permi Urala, Priural'ya i Srednei Azii* (Boundary Carboniferous–Permian Deposits of the Urals, Cis-Urals, and Central Asia), Moscow: Nauka, 1986, pp. 21 - 29.

Cowie, J.W., Guidelines for Boundary Stratotypes, *Episodes*, 1986, vol. 9, no. 2, pp. 78 - 82.

Davydov, V.I., *Daixina bosbytauensis–D. robusta* Zone in Southern Fergana, *Dokl. Akad. Nauk SSSR*, vol. 298, no. 4, 1987, pp. 160 - 164.

Davydov, V.I., Finds of *Nodosaria* in the Upper Carboniferous Deposits of Darvaz, *Dokl. Akad. Nauk SSSR*, vol. 290, no. 4, 1986a, pp. 913 - 916.

Davydov, V.I., Gzhelian Zonal Subdivision in the Donets Basin and the Cis-Donets Trough according to Fusulinids, *Trudy 34 Sessii VPO* (Proc. 34th Session of the All-Union Paleontological Soc.), Leningrad: Nauka, 1990, pp. 52 - 69.

Davydov, V.I., Subdivision and Correlation of the Upper Carboniferous and Lower Permian Deposits in the Donets Basin and Cis-Donets Trough, *Sov. Geol.*, 1992, no. 5, pp. 53 - 61.

Davydov, V.I., To the Positional Verification of the Carboniferous–Permian Boundary in the Donets Basin and Northern Caucasus according to Paleomagnetic Data, *Sov. Geol.*, 1986b, no. 12, pp. 74 - 76.

Davydov, V.I., Upper Carboniferous Zonal Subdivisions of South-Western Darvaz, *Byull. MOIP, Otd. Geol.*, 1984, vol. 59, issue 3, pp. 41 - 57.

Davydov, V.I., Barskov, I.S., Bogoslovskaya, M.F., Leven, E.Ya., Popov, A.V., Akhmetshina, L.Z., and Kozitskaya, R.I., The Carboniferous–Permian Boundary in the Former USSR and Its Correlation, *Int. Geol. Rev.*, 1992, vol. 34, no. 10, pp. 889 - 906.

Davydov, V.I., Bogoslovskaya, M.F., Popov, A.V., Akhmetshina, L.Z., Barskov, I.S., Kozitskaya, R.I., Kotlyar, G.V., and Leven, E.Ya., The Solution to the Problem of the Carboniferous–Permian Boundary in the USSR, *Permophiles*, 1990, no. 17, pp. 9 - 13.

Davydov, V.I, Popov, A.V., Bogoslovskaya, M.F., *et al.*, Aidaralash Section. Permian System of the World. Excursion Guide, part II, issue 2, *Razrezy Permskoi Sistemy Basseina Reki Ural* (Permian Sections of the Ural River Basin), Sverdlovsk: UrO Akad. Nauk SSSR, 1991, pp. 54 - 84.

Davydov, V.I. and Popov, A.V., Upper Carboniferous and Lower Permian Sections of the South Urals, *Pogranichnye Otlozheniya Karbona i Permi Urala, Priural'ya i Srednei Azii* (Carboniferous and Permian Boundary Deposits of the Urals, Cis-Urals and Central Asia), Moscow: Nauka, 1986, pp. 29 - 33.

Ekhlakov, Yu.A. and Zolotova, V.P., Sections of Carboniferous–Permian Boundary Deposits in the Ostanets Section on the Kos'va and Berezovaya Rivers, *Pogranichnye Otlozheniya Karbona i Permi Urala, Priural'ya i Srednei Azii* (Boundary Carboniferous–Permian Deposits of the Urals, Cis-Urals and Central Asia), Moscow: Nauka, 1986, pp. 12 - 18.

Furnish, W.M. and Glenister, B.F., Permian Goniolobocerati-dae (Ammonodea), *Smyths. Contrib. Paleobiol.*, 1971, no. 3, pp. 301 - 312.

Henderson, Ch.M., Carboniferous–Permian Boundary Studies in the Canadian Arctic Archipelago, *U.S. Geol. Surv. Open-File Rep.*, 1990, nos. 90 - 233, pp. 12 - 19.

Kalmykova, M.A., The Carboniferous–Permian Boundary, *Verkhnii Karbon SSSR, Trudy MSK* (Upper Carboniferous of

the USSR, Proc. Interdepartment Stratigraphy Committee), Moscow: Nauka, 1984, vol. 13, pp. 113 - 118.

Khramov, A.N. and Davydov, V.I., Paleomagnetic Characteristics of Type Upper Carboniferous and Lower Permian Sections of the South Urals, *Permskaya Sistema Zemnogo Shara, Putevoditel' Geologicheskikh Ekskursii* (The Permian System of the World, Guide of Geological Excursions), part II, issue 2, Sverdlovsk: UrO Akad. Nauk SSSR, 1991, pp. 85 - 93.

Kireeva, G.D., Shcherbovich, S.F., Dobrokhotova, S.V., *et al.*, Asselian Zone of *Schwagerina vulgaris–Schw. fusiformis* on the Russian Platform and on the Western Slope of the South Urals, *Voprosy Mikropaleontologii*, Moscow: Nauka, 1971, issue 14, pp. 70 - 102.

Konovalova, M.V., *Stratigrafiya i Fuzulinidy Verkhnego Karbona i Nizhnei Permi Timano-Pechorskoi Neftegazonosnoi Provintsii* (Upper Carboniferous–Lower Permian Stratigraphy and Fusulinids in the Timan'–Pechora Oil-and-Gas-Bearing Province), Moscow: Nedra, 1991.

Leven, E.Ya., The *Daixina bosbytauensis–Daixina robusta* Zone and the Problem of the Carboniferous–Permian Boundary, *Pogranichnye Otlozheniya Karbona i Permi Urala, Priural'ya i Srednei Azii* (Carboniferous–Permian Boundary Deposits of the Urals, Cis-Urals and Central Asia), Moscow: Nauka, 1986, pp. 48 - 55.

Leven, E.Ya. and Davydov, V.I., On the Boundaries and Volume of the Lower Asselian Zone, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1991, no. 12, pp. 61 - 73.

Leven, E.Ya. and Davydov, V.I., The Sequence of the Boundary Carboniferous–Permian Beds in Darvaz and Its Implication for Solving the Problem of the Carboniferous–Permian Boundary, Abstract of Papers, *9th ICCs, Urbana, Illinois, U.S.A.*, 1979, pp. 116 - 117.

Leven, E.Ya. and Davydov, V.I., The Upper Carboniferous and Permian Boundary Deposits of Darvaz, *Pogranichnye Otlozheniya Karbona i Permi Urala, Priural'ya i Srednei Azii* (Carboniferous–Permian Boundary Deposits of the Urals, Cis-Urals and Central Asia), Moscow: Nauka, 1986, pp. 33 - 48.

Leven, E.Ya. and Shcherbovich, S.F., *Fusulinidy i Stratigrafiya Assel'skogo Yarusa Darvaza* (Asselian Fusulinids and Stratigraphy of Darvaz), Moscow: Nauka, 1978.

Leven, E.Ya. and Sosipatrova, G.P., Foraminifers, *Osnovnye Cherty Stratigrafii Permskoi Sistemy* (The Main Stratigraphic Features of the Permian System), Leningrad: Nedra, 1984, pp. 241 - 245.

Mikhailova, Z.P., *Fuzulinidy Verkhnego Karbona Pechorskogo Priural'ya* (Upper Carboniferous Fusulinids of the Pechora Cis-Urals), Leningrad: Nauka, 1974.

Movshovich, E.V., Kotsur, Kh., Pavlov, A.M., *et al.*, Lower Permian Conodont Assemblages of the Cis-Urals and Correlation Problems of Lower Permian Deposits, *Konodonty Urala i Ikh Stratigraficheskoe Znachenie, Trudy Instituta Geologii i Geokhimii, UrO Akad. Nauk SSSR* (Conodonts of the Urals and Their Stratigraphic Significance, Proc. Inst. Geology and Geochemistry, Ural Branch Acad. Sci. of the USSR), 1979, issue 145, pp. 94 - 125.

Murav'ev, I.S., Ermoshkin, N.V. and Shulikov, E.S., *Verkhnekamennougol'nye i Nizhnepermskie Otlozheniya Samarskoi Luki* (Upper Carboniferous and Lower Permian Deposits of the Samara Luka Area), Kazan: Kazan. Univ., 1983.

Myers, D.A., Stratigraphic Distribution of Fusulinid Foraminifera from the Manzano Mountains, New Mexico, *U.S. Geol. Surv. Prof. Papers*, 1988, no. 144-A, B, pp. 134 - 140.

Nilsson, I., *Carboniferous and Permian Fusulinids on the Nordfjorden Block*, Spitsbergen (Svalbard), Thesis., Univ. Oslo, 1988.

Nilsson, I. and Davydov, V.I., Abstract of Papers, *Middle Carboniferous–Lower Permian Fusulinid Stratigraphy in Spitsbergen, Arctic Norway – a Framework for Correlation in the Arctic*, Pangea-Meeting, Calgary, 1993.

Nogami, Y., Jungpalaeozoikum in Atetsu-Plateau, Sudwestjapan, *Mem. Coll. Sci. Univ. Kyoto. Ser. B.*, 1962, vol. 29, no. 2, pp. 161 - 176.

Nogami, Y., Permische Fusuliniden aus dem Atetsu-Plateau Sudwestjapan, Teil 1, Fusulininae und Schwagerininae, *Mem. Coll. Sci. Univ. Kyoto. Ser. B.*, 1961, vol. 28, no. 2, pp. 159 - 248.

Opornyi Razrez Pogranichnykh Sloev Karbona i Permi Yuga Vostochno-Evropeiskoi Platformy (Reference Section of Carboniferous–Permian Boundary Layers of the East European Platform Southern Part), Leningrad: Nauka, 1983.

Ovnatanova, N.S. and Akhmetshina, L.Z., Carboniferous–Lower Permian Scale of the Caspian Depression (According to Conodonts), *Stratigrafiya i Paleontologiya Paleozoya Prikaspiiskoi Vpadiny* (Paleozoic Stratigraphy and Paleontology of the Caspian Depression), Moscow: VNIGNI (All-Union Geological and Oil Inst.), 1987, pp. 103 - 114.

Permophiles, *A Newsletter of SCPS*, no. 17, November, 1990.

Permophiles, *A Newsletter of SCPS*, no. 21, November, 1992.

Pnev, V.P., Polozova, A.N., Pavlov, A.M., and Faddeeva, I.Z., On the Stratotype Section of the Orenburgian Stage, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1975, no. 5, pp. 100 - 109.
Pnev, V.P., Polozova, A.N., Pavlov, A.M., and Faddeeva, I.Z., The Aidaralash Section – the Asselian Reference Section, *Stratigrafiya i Paleontologiya Urala i Aziatskoi Chasti SSSR* (Stratigraphy and Paleontology of the Urals and of the Asian USSR), *Zapiski Len. Gos. Univ.*, 1978, vol. 37, issue 2, pp. 90 - 98.

Pogranischnye Otlozheniya Karbona i Permi Urala, Priural'ya i Srednei Azii (Carboniferous–Permian Boundary Deposits of the Urals, Cis-Urals and Central Asia), Moscow: Nauka, 1986.

Popov, A.V., Davydov. V.I., Donakova, L.M., and Kossovaya, O.L., To the Gzhelian Stratigraphy of the South Urals, *Sov. Geol.*, 1985, no. 3, pp. 57 - 67.

Popov, A.V., Davydov, V.I., and Kossovaya, O.L., *Stratotipy i Fauna Unifitsirovannykh Gorizontov Verkhnego Karbona i Nizhnei Permi Srednei Azii* (Stratotypes and Fauna of Unified Upper Carboniferous and Lower Permian Horizons of Central Asia), Available from VINITI, Leningrad, 1987, no. 2434-B-87.

Popov, A.V., Davydov, V.I., and Kossovaya, O.L., To the Gzhelian Stratigraphy of Central Asia, *Sov. Geol.*, 1989, no. 3, pp. 64 - 76.

Postanovleniya Mezhvedomstvennogo Stratigraficheskogo Komiteta i Ego Postoyannykh Komissii (Resolutions of the Interdepartment Stratigraphic Committee and Its Standing Commissions), 1984, Leningrad: VSEGEI (All-Union Geological Institute), issue 22, pp. 44 - 48.

Postanovleniya Mezhvedomstvennogo Stratigraficheskogo Komiteta i Ego Postoyannykh Komissii (Resolutions of the Interdepartment Committee and Its Standing Commissions), 1992, Leningrad: VSEGEI (All-Union Geological Institute), issue 26, pp. 52 - 56.

Rauser-Chernousova, D.M., Foraminifers from the Stratotype Sakmarian Section, *Tr. GIN Akad. Nauk SSSR*, 1965, vol. 135.

Rauser-Chernousova, D.M., The Carboniferous–Permian Boundary, *Granitsy Geologicheskikh Sistem* (The Boundaries of Geological Systems), Moscow: Nauka, 1976, pp. 111 - 125.

Rauser-Chernousova, D.M. and Shchegolev, A.K., The Carboniferous–Permian Boundary in the USSR, *Biostratigrafiya Pogranichnykh Otlozhenii Karbona i Permi* (Biostratigraphy of the Carboniferous–Permian Boundary Deposits), Moscow: Nauka, 1980, pp. 52 - 69.

Ritter, S.M., Stratigraphic Distribution of Late Carboniferous and Early Permian (Gzhelian–Asselian) Conodonts in the Midcontinental Sections of the USA and Preliminary Correlation with the Conodont Sequence of Russia, *Tezisy Dokladov Mezhdunarodnogo Kongressa "Permskaya Sistema Zemnogo Shara"* (Abstracts of Papers, Int. Congr. "Permian System of the World", Sverdlovsk: UrO Akad. Nauk SSSR, 1991.

Ross, Ch.A., Fusulinacean Zonation across the Carboniferous–Permian Boundary in North America, *Biostratigrafiya Pogranichnykh Otlozhenii Karbona i Permi* (Biostratigraphy of Carboniferous-Permian Boundary Deposits), Moscow: Nauka, 1980, pp. 124 - 142.

Rui Lin, Zhang Linxin, Wang Zhihao, and Wang Jianhua, Notes on the Carboniferous–Permian Boundary in South China, *Compt. Rendu. XI ICC*, Beijing, 1987, 1989, vol. 2, pp. 239 - 250.

Ruzhentsev, V.E., Biostratigraphy of the Sakmarian Stage in the Aktyubinsk Region of the Kazakh SSR, *Trudy PIN Akad. Nauk SSSR*, 1952, vol. 42.

Ruzhentsev, V.E., Lower Permian Ammonites of the South Urals. I. Sakmarian Ammonites, *Tr. PIN Akad. Nauk SSSR*, 1951, vol. 33, pp. 1 - 188.

Ruzhentsev, V.E., Paleontological Notes on Carboniferous and Permian Ammonoids, *Prob. Sov. Geol.*, 1936, no. 12, pp. 1072 - 1088.

Ruzhentsev, V.E., Upper Carboniferous Ammonites of the Urals, *Trudy PIN Akad. Nauk SSSR*, 1950.

Sada K., Carboniferous and Permian Stratigraphy of the Atetsu Limestone in West Japan, *J. Sci. Hiroshima Univ.*, 1965, Part C, vol. 4, no. 3, pp. 225 - 269.

Semina, S.A., Stratigraphy and Foraminifers (Fusulinids) from the Schwagerina Horizon of the Oka–Tsna Uplift, *Trudy GIN Akad. Nauk SSSR*, 1961, issue 57.

Shcherbakova, M.V., Carboniferous–Permian Boundary Beds on the Kos'va River, *Pogranichnye Otlozheniya Karbona i Permi Urala, Priural'ya i Srednei Azii* (Boundary Carboniferous–Permian Deposits of the Urals, Cis-Urals and Central Asia), Moscow: Nauka, 1986, pp. 18 - 21.

Shcherbovich, S.F., Late Gzhelian and Asselian Fusulinids from the Cis-Caspian Sea Syneclise, *Trudy GIN Akad. Nauk SSSR*, 1969, issue 176.

Shkolin, A.A., New Ammonoid Species of the Genus *Juresanites* from the Lower Permian of the South Urals, *Paleontolog. Zh.*, 1993, no. 4, pp. 69 - 72.

Sobolev, N.N., Nakrem, H.A., Middle Carboniferous–Lower Permian Conodonts from Novaya Zemlya, *IKU Rep.*, no. 23.1438.05/01.92, 1992.

Toriyama, R., The Fusulinacean Zones of Japan, *Mem. Fac. Sci. Kyushu Univ., Ser. D. Geology*, 1967, vol. 28, no. 1.

Wang Zhi-Hao, Conodonts from Carboniferous–Permian Boundary Strata in China with Comments on the Boundary, *Acta Paleontol. Sinica*, 1991, vol. 30, no. 1, pp. 18, 36 - 39.

Watanabe, K., Fusuline Biostratigraphy of the Upper Carboniferous and Lower Permian of Japan, with Special Reference to the Carboniferous–Permian Boundary, *Paleontol. Soc. Jpn. Spec. Pap.*, 1991, no. 32.

Wilde, G.L., Practical Fusulinid Zonation: The Species Concept, with Permian Basin Emphasis, *Bull. Geol. Soc. West Texas*, 1990, vol. 29, no. 7, pp. 5 - 15, 28 - 34.

Wilde, G.L., Systematic and the Carboniferous–Permian Boundary, *Biostratigraphy, Neuvieme Congres International de Stratigraphie et de Geologie du Carbonifere: Carbondale and Edwarsville*, Sutherland, P.K. and Manager, W.L., Eds., Illinois, Southern Illinois Univ., 1984, vol. 2, pp. 543 - 558.

Xiao Weimin, Wang Hongdi, Zhang Linxin, and Dong Wenlan, *Early Permian Stratigraphy and Faunas in Southern Guizhou*, People's Publ. House of Guizhou, 1986.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 244 - 248. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 46 - 50.
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Zonal Subdivision of Visean and Serpukhovian Deposits of the Moscow Depression on the Basis of Foraminifera

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Abstract – Foraminiferal assemblages of stratotype regions of the Moscow depression have been studied. This allowed us to establish stratotypes for foraminiferal zones recognized earlier by Lipina and Reitlinger. Zonal boundaries have been refined and an extensive investigation was devoted to zonal associations.

Early Carboniferous foraminiferal zones were first established in this country by O.A. Lipina and E.A. Reitlinger in 1970. They were mainly based on the stratigraphic distribution of foraminiferas in the Moscow depression, the Volga–Ural region, Urals, and other regions. These subdivisions are complex zones (*Stratigraficheskii Kodeks* ..., 1977). Each zone is characterized by a unique foraminiferal assemblage that reccurs neither in overlying, nor in underlying deposits. The appearance of index species is principally registered at the zone's base. Sometimes index species are already present in the upper part of the lower, i.e., older zone. For example, the species *Eostaffella ikensis* appears in the upper part of the zone *Eostaffella proikensis–Archaediscus gigas*. All the zones completely coincided with horizons of the Unified Scheme of the Russian platform (*Resheniya* ..., 1965). Later on names of index species of several zones were somewhat changed, though the volume of the zones remained unchanged (Vdovenko, 1986, 1988; Lipina, 1973; *Putevoditel'*..., 1975). Zone stratotypes have not been established.

In 1989 - 1990 I conducted a layer-by-layer study of foraminiferal communities in a number of hypostratotype sequences of the Lower Carboniferous of the Moscow depression. I studied them in thin sections that were kindly provided by M.Kh. Makhlina and V.E. Zhulitova, to whom I am greatly indebted. This study made it possible to establish stratotypes for many earlier recognized zones of the Moscow depression (Lipina and Reitlinger, 1970). The study has also enabled us to more precisely define zonal boundaries and extensively describe zonal associations. Limited space prevents consideration of the lithology of the zones, their thickness and so on. This data has been already published (Makhlina and Zhulitova, 1984; Makhlina and Shik, 1986; *Putevoditel'* ..., 1975, *Resheniya* ..., 1990).

Seven zones were originally established in the Visean Stage (Lipina and Reitlinger, 1970). Only five of them are known in the Moscow depression because of an incomplete Lower Carboniferous sequence in the depression (*Putevoditel'* ..., 1975).

The *Endothyranopsis compressa–Archaediscus krestovnikovi* Zone, the first foraminiferal zone of the Visean Stage in the Moscow depression, was earlier thought to correspond completely to the Tula Horizon (the table). The lower part of the horizon lacks foraminiferas. The first foraminiferal assemblages of the Tula Horizon are known in the first occurring limestones of the horizon. They were found approximately in the middle part of the horizon, a Bogoroditsk Subformation of the Tula Formation (Makhlina and Zhulitova, 1984, *Resheniya* ..., 1990; Fomina, 1960). I studied these assemblages from the materials of the Bogoroditsk and Gryzlovo quarries.

I suggest an interval from the base of first limestone occurrence of the Tula Horizon to the base of the Aleksin Horizon in the sequence of Bogoroditsk quarry (hypostratotype of the Tula Horizon) to be considered a stratotype of the *Endothyranopsis compressa–Archaediscus krestovnikovi* Zone. Thus, the stratotype comprises a larger part of the Bogoroditsk Subformation and the Ol'khovets Subformation of the Tula Formation (Makhlina and Zhulitova, 1984; *Resheniya* ..., 1990). It should be noted that there is a gap between the considered zone and the underlying *Ammarchaediscus primaevus–Uralodiscus rotundus* Zone, which in the Moscow depression is represented by continental deposits.

Originally the faunal content of the zone included *Endothyranopsis compressa* (Rauser et Reitl.) species of *Lituotubella, Haplophragmella, Endothyra bowmani* Phillips, *Omphalotis minima* (Rauser et Reitl.), numerous *Archaediscus krestovnikovi* Rauser, *Eostaffella*, and *Parastaffella* (Lipina and Reitlinger, 1970).

The lower boundary of the *Endothyranopsis compressa–Archaediscus krestovnikovi* Zone corresponds in its stratotype to the appearance of the index species *Endothyranopsis compressa* (Rauser et Reitl.), various *Palaeotextularia, Endostaffella, Urbanella miranda*

Scheme of zonal subdivision of Visean and Serpukhovian deposits of the Moscow depression

Stage	Substage	Horizon (*Resheniya ..., 1965*)	Formation (Makhlina and Shik, 1986; *Resheniya ..., 1990*)	Subformation (Makhlina and Shik, 1986; *Resheniya ..., 1990*)	Foraminiferal zone (*Putevoditel' ..., 1975*; Lipina and Reitlinger, 1970)	Foraminiferal zone (Vdovenko, 1986, 1988)	Proposed correlation. Zone, subzone
Serpukhovian	Upper	Protva	Protva	Sandovo Luzha Kremenskoe	*Eostaffellina protvae*	*E. protvae*	*E. protvae*
	Lower	Steshevo	Steshevo	Dashkovo Glazechnya	*Eostaffellina decurta*	*Pseudoendothyra globosa–Neoarchaediscus parvus*	*E. decurta* (*P. globosa–N. parvus*)
		Tarusa	Tarusa	Bekhovo Ignatova Gora	*Pseudoendothyra illustria–P. globosa*		*P. illustria* *P. globosa* (*P. globosa–N. parvus*)
		Venev	Venev	Sukhodol Novogurovskii	*Eostaffella tenebrosa*	*E. tenebrosa–Endothyranopsis sphaerica*	*E. tenebrosa–E. sphaerica*
Visean	Upper	Mikhailov	Mikhailov	Kumova Gora Erino Serebryanyi	*E. ikensis*	*E. ikensis*	*E. ikensis*
		Aleksin	Aleksin	Parsuki Myshiga Stopkino	*Eostaffella proikensis–Archaediscus gigas*	*E. proikensis–A. gigas*	*E. proikensis–A. gigas*
		Tula	Tula	Ol'khovets Bogoroditsk Shchekino	*Endothyranopsis compressa*	*E. compressa–Archaediscus krestovnikovi*	*E. compressa–A. krestovnikovi*
	Lower	Bobriki	Bobriki				

(Rauser) group, *Eostaffella* with ovoid periphery (*E. mosquensis*), and *Parastaffella*. Thus, *Palaeotextularia longisepta* Lipina,[1] *P. consobrina* Lipina,[1] *Forschia*, small *Omphalotis* and *Globoendothyra*, *Endothyranopsis compressa* (Rauser et Reitl.),[1] *Archaediscus krestovnikovi* Rauser, *Endostaffella*[1], *Eostaffella mosquensis* Vissarionova,[1] sparse primitive *Plectostaffella* (?) sp., and *Eostaffellina* (?) sp.,[1] *Mediocris*, *Parastaffella candida* Ganelina,[1] and other forms are known from the base of the zone onward. The listed forms are accompanied by *Earlandia*, *Pseudoammodiscus priscus* (Rauser), various *Endothyra*, and others. Isolated occurrences of "Early Visean" genera and subgenera, like *Eoparastaffella*, smaller *Dainella*, and *Eogloboendothyra*, are also noted. The latter forms occur mainly in the lower part of the zone, corresponding to the Bogoroditsk Subformation of the Tula Formation. Stenobiontic forms, like *Lituotubella glomospiroides* Rauser, first occurring *Cribrospira*[1] and *Haplophragmella*,[1] larger *Globoendothyra*,[1] and other forms appear in the upper half of the zone that corresponds to the Ol'khovets Subformation of the Tula Formation. This zone is thus correlated with the middle and upper parts of the Tula Horizon (the table).

[1] In adjacent regions the form is not recorded in the underlying zone

The following *Eostaffella proikensis–Archaediscus gigas* Zone correlates with the Aleksin Horizon (*Putevoditel' ...*, 1975; Lipina and Reitlinger, 1970) of the 1962 Unified Scheme. It was originally defined by the appearance of genera and species unknown in underlying deposits. These forms are *Bradyina*, *Endothyranopsis crassa* (Brady), larger *Archaediscus* (*A. gigas* Raus.), and *Howchinia gibba* (Moeller), first occurring *Asteroarchaediscus* and *Neoarchaediscus*, and subrhombic *Eostaffella proikensis* Rauser.

Foraminiferal assemblages of this zone were studied in thin sections from hypostratotype sequences of the Aleksin Horizon of the Bogoroditsk, Polotnyanyi Zavod, and "Spartak" (near Mikhailov) quarries. In the Bogoroditsk quarry, in addition to deposits of the Tula Horizon (*Endothyranopsis compressa–Archaedissus krestovnikovi* Zone) the lowermost part of the Aleksin Horizon outcrops. It corresponds to the Stopkino Subformation of the Aleksin Formation. This part of the sequence is poorly characterized by foraminifers. Index species of the *Eostaffella proikensis* and *Archaediscus gigas* Zone are not found here.

The Myshiga Subformation of the Aleksin Formation in the Polotnyanyi Zavod quarry is suggested as the stratotype of the *Eostaffella proikensis–Archaediscus gigas* Zone (*Resheniya ...*, 1990). So, the lower bound-

ary of the zone is defined in the stratotype by the appearance of the index species *E. proikensis* Rauser, and *A. gigas* Rauser at the base of the zone. They are accompanied by *Bradyina*, relatively large *Omphalotis* species, and first *Calcifolium* algae. The zone is also characterized by the presence of *Lituotubella magna* Rauser, *Cribrospira*, species of *Palaeotextularia, Forschia, Haplophragmella*, and others. Some forms that have been previously reported in the zone (Lipina and Reitlinger, 1970) were either not found, as *Neoarchaediscus*, or their finds are very rare and questionable, as is the case of *Asteroarchaediscus*.

The upper part of the Aleksin Horizon is marked by the appearance of sparse *Climacammina, Janischewskina*, rare *Eostaffella ikensis, Omphalotis omphalota* (Rauser et Reitlinger), and *Mirifica*. According to Reitlinger (Lipina and Reitlinger, 1970) all these forms are typical of the overlaying *Eostaffella ikensis* Zone. The appearance of listed forms in the upper part of the Aleksin Horizon was noted by Rauser-Chernousova in 1948.

Therefore, the *Eostaffella proikensis–Archaediscus gigas* Zone correlates to the middle part of the Aleksin Horizon, the Myshiga Subformation, but not with the entire Aleksin Horizon (the table).

The third zone, i.e., the *Eostaffella ikensis* Zone, was previously correlated only with the Mikhailov Horizon. Originally the zone was defined by the appearance of *Janischewskina, Climacammina*, abundant *Endothyranopsis, Omphalotis, Bradyina, Howchinia gibba* (Moeller), and *Archaediscus karreri* Brady. *Neoarchaediscus parvus* (Raus.) and *Asteroarchaediscus rugosus* (Raus.) become relatively common (Lipina and Reitlinger, 1970).

Foraminiferal assemblages from subsequent layers of the zone were studied in samples collected layer-by-layer from hypostratotype sequences of the Polotnyanyi Zavod and "Spartak" quarries. The stratotype of the zone is proposed in the "Spartak" quarry. The zone is comprised of the Parsuki Subformation of the Aleksin Horizon, and Serebryannyi, Erino, and Kumova Gora Subformations of the Mikhailov Horizon (the table).

The lower boundary of the *Eostaffella ikensis* Zone is indicated by an appearance of new rare specimens of the index species together with isolated occurrences of *Climacammina, Janischewskina, Omphalotis omphalota* (Rauser et Reitlinger), and *Mirifica mirifica* (Rauser).

The *Eostaffella ikensis* Zone is marked by high specific and generic diversity of foraminifers. Here, apart from the forms listed above, the following forms are encountered: *Lituotubella*, various *Endothyra, Omphalotis, Globoendothyra, Plectogyranopsis, Howchinia gibba* (Moeller), numerous *Archaediscus, Eostaffella*, rare *Asteroarchaediscus*, rare or isolated occurrences of *Pojarkovella* ex gr. *nibelis* (Durkina), *Spinothyra, Endospiroplectammina syzranica* (Lipina), and many other forms.

Thus, I propose correlating the *Eostaffella ikensis* Zone with the uppermost part of the Aleksin Horizon, (the Parsuki Subformation) and the Mikhailov Horizon.

The forth zone, the *Eostaffella tenebrosa–Endothyranopsis sphaerica* Zone was initially proposed as the *Eestattella tenebrosa* Zone (Lipina and Reitlinger, 1970). In 1986, the present name was given to the zone without changing its volume (Vdovenko, 1986, 1988). The zone was originally defined by a presence of frequently occurring *Endothyranopsis sphaerica* (Rauser et Reitl.), *Eostaffella parastruvei* Rauser, *E. tenebrosa* Rauser and *Endostaffella parva* (Moell.), and a first occurrence of *Asteroarchaediscus rugosus* (Rauser) and *Neoarchaediscus parvus* (Rauser) (Lipina and Reitlinger, 1970).

A layer-by-layer study of foraminiferal assemblages was conducted in a thin section of material sampled from hypostratotype sequences of the Venev Horizon in the Gur'ev, Ignatova Gora, Polotnyanyi Zavod, and "Spartak" quarries. The Venev Horizon (the Novogurovskii and the Sukhodol Subformations of the Venev Formation) in the Gur'ev (Venev) quarry is proposed as the stratotype of the zone.

The lower boundary of the zone is defined by the appearance of zonal index species together with isolated occurrences of *Planoendothyra aljutovica minor* Rosovskaja, *Eostaffella* ex gr. *pseudostruvei* Rauser et Beljaev, and *Parastaffella propinqua* Rauser.

At the same time forms of the underlying zone are still present. They include diverse *Endothyra, Omphalotis* (including *O. omphalota* (Rauser et Reitlinger)), *Globoendothyra*, and *Endothyranopsis crassa* (Brady). Some forms are less numerous in comparison to the underlying level. They are *Bradyina, Janischewskina, Cribrospira, Archaediscus* (including a less abundant than in underlying deposits *A. gigas*), *Asteroarchaediscus rugosus* (Rauser), *Endostaffella, Howchinia, Loeblichia*, and various *Eostaffella*. The Algae *Calcifolium punctatum* are less frequent. The upper part of the zone is marked by isolated occurrences of *Eostaffellina*.

THE SERPUKHOVIAN STAGE

At first two zones were established in the lower substage of the Serpukhovian Stage (Lipina and Reitlinger, 1970). Later they were united into a single zone (Vdovenko, 1986, 1988) (the table). Initially the lower *Pseudoendothyra illustria–Pseudoendothyra globosa* Zone was characterized by most typical *Endothyra bowmani* Phillips, *Endothyranopsis sphaerica* (Rauser et Reitl.), a group of *Archaediscus krestovnikovi* Rauser, *Asteroarchaediscus rugosus* (Rauser), *Neoarchaediscus parvus* (Rauser), a group of *Endostaffella parva* (Moeller), *Biseriella parva* (N. Tchernysheva), *Eostaffella parastruvei* Rauser, *E. pseudostruvei* Rauser et Beljaev, and first occurrences of *Pseudoendothyra globosa* Rosovskaja. An assemblage of the following *Eostaffellina decurta* Zone is very close to the previous one. It differs in the appearance of *Eostaffellina decurta* (Rauser), *Bradyina* ex gr. *cribrostomata*

Rauser et Reitlinger and *Globivalvulina*. These zones have been respectively correlated with the Tarusa and the Steshevo horizons.

The foraminiferal assemblage of the *Pseudoendothyra globosa–Neoarchaediscus parvus* Zone that were established in 1986 (Vdovenko, 1986) were studied in the samples from the Zabor'e, Ignatova Gora, and Gur'ev quarries.

The lower boundary of the zone is indistinct. Reitlinger (Lipina and Reitlinger, 1970) noted an absence of abrupt changes in the composition of the foraminiferal assemblage at the base of the zone. The most characteristic is an appearance of *P. globosa*.

Deposits of the zone contain *Palaeotextularia, Climacammina, Endothyra, Omphalotis* ex gr. *omphalota* (Rauser et Reitlinger) and other species of *Omphalotis, Endothyranopsis crassa* (Brady), *E. sphaerica* (Rauser et Reitlinger), *Archaediscus krestovnikovi* Rauser, *A. chernoussovensis* Mamet, *Asteroarchaediscus* ex gr. *baschkiricus* (Krestovnikov et Theodorovich), *Neoarchaediscus*, including an index species *N. parvus* (Rauser), *Endostaffella, Loeblichia, Euxinita, Endotaxis* (?), diverse *Eostaffella*, including *E.* ex gr. *pseudostruvei* Rauser et Beljaev, *E.* ex gr. *postmosquensis* Kireeva, *Plectostaffella, Eostaffellina*, and other forms. *Calcifolium* algae are less frequent than in the previous zone. The index species *P. globosa* was not encountered in the sequences studied. Nevertheless, the analysis of foraminiferal assemblages allows us to refer the enclosing deposits to this zone. Unlike other parts of the Russian Plain, where the present scheme is used, two subzones of the zone in question can still be recognized in the Moscow depression. They are the *Pseudoendothyra illustria–Psendoendothyra globosa* Subzone and the *Eostaffellina decurta* Subzone. As was already noted, both units were established by Reitlinger in 1970 as separate zones.

The stratotype of *Pseudoendothyra illustria–Pseudoendothyra globosa* Subzone is proposed in the Ignatova Gora (Tarusa) quarry in the volume of the Tarusa Formation (Ignatova Gora and Bekhovo Subformations). The foraminiferal assemblage of this subzone is characterized by a gradual disappearance of larger stenobiontic forms, like *Cribrospira, Omphalotis omphalota*, and others. Euryobiontic "smaller" foraminifers, like *Euxinita, Betpakodiscus* (?), and *Asteroarchaediscus*, are more frequent than in underlying deposits. There are isolated occurrences of forms typical of overlying deposits, such as *Biseriella parva* (N. Tchernysheva) and *Plectostaffella*, and *Eostaffella* of the *E. pseudostruvei* Rauser et Beljaev group are recorded. Subzone index species was not found.

The Steshevo Formation (the Glazechnya and Dashkovo subformations) in the Zabor'e quarry is proposed as the stratotype of the *Eostaffellina decurta* Subzone. Main features of the foraminiferal assemblage of the subzone were presented above using published data (Lipina and Reitlinger, 1970). The presently studied materials show the following differences between the subzone's complex of foraminifers and those of underlying units. The disappearance of stenobiontic forms and the increase in eurybiontic ones continues. In addition, a number of forms typical of overlying deposits are registered. These are more abundant and diverse *Neoarchaediscus*, isolated occurrences of *Endotaxis, Planospirodiscus* (?), *Eostaffella* ex gr. *postmosquensis* Kireeva, and others.

Reitlinger (Lipina and Reitlinger, 1970) was the first to establish the *Eostaffellina protvae* Zone, correlating it with the Protva Horizon. According to its original definition, the foraminiferal assemblage contains both Visean and first occurring "Protva" species, including *Bradyina cribrostomata* Rauser et Reitlinger, *Janischewskina calceus* (Ganelina), *Asteroarchaediscus baschkiricus* (Krestovnikov et Theodorovich), *Eostaffella ikensis* Vissarionova, *E. pseudostruvei* Rauser et Beljaev, *Eostaffellina protvae* (Rauser), *Pseudoendothyra globosa* Rosovskaja, and *P. parashaerica* Reitlinger.

I studied the zone foraminifers from the sequences of the Zabor'e, Rozhdestvo, and Uglovka quarries. The Protva Formation, including its Kremenskoe, Luzha, and Sandovo Subformations in the Rozhdestvo quarry is proposed to be the zonal stratotype (*Resheniya ...*, 1990). It should be noted that in the Rozhdestvo quarry, as well as in the Uglovka quarry, there is no direct contact between the described zone and the underlying one. Nevertheless, this exposure presents the most complete sequence of the zone's deposits with diverse foraminiferal assemblages. Though deposits of the underlying zone are known in the Zabor'e quarry, only the lower part of the *Eostaffellina protvae* Zone is present there.

The lower boundary of this zone is defined by the appearance of index species together with *E. paraprotvae* (Rauser), *E. subsphaerica* (Gan.), *E. monstruosa* Reitl., *Pseudoendothyra parasphaerica* Reitl., and *Ps. continens* Ros. The lower boundary of the zone stratotype coincides with the base of the Protva Horizon.

In addition to the species listed above the following forms are encountered in studied sequences: rare *Palaeonubecularia* and *Pseudoglomospira*, large *Earlandia, Palaeotextularia, Climacammina*, diverse *Endothyra, Globoendothyra globula* (Eichwald), *G. numerabilis* (Vissarionova), *Endothyranopsis sphaerica* (Rauser et Reitlinger), *E. crassa* (Brady), *Bradyina cribrostomata* Rauser et Reitlinger, *Janischewskina, Archaediscus* and *Asteroarchaediscus*, larger *Eostaffella ikensis* Vissarionova, *E. paleostruvei* Rauser, *E. postmosquensis* Kireeva, *Plectostaffella* ex gr. *varvariensis* (Brazhnikova et Potjevskaja), *Pseudoendothyra globosa* Rosovskaja, and other forms. Foraminifers are more abundant in the lower part of the zone that corresponds to the Kremenskoe Subformation of the Protva Formation (*Resheniya ...*, 1990). In the middle and upper parts of the zone, which correspond to the Luzha and the Sandovo subformations, the composition of the foraminiferal assemblages is more uniform, however the index species and other "Protva" forms continue to be present.

This zone is correlated with the Protva Horizon (the table).

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REFERENCES

Fomina, E.V., About Relation of Upper and Lower Tulian Foraminiferal Assemblages to Various Carbonate Facies of the Tulian Basin, *Voprosy Mikropaleontol.*, 1960, no. 3, pp. 67 - 71.

Lipina, O.A., Zonal Stratigraphy and Paleobiogeography of the Tournasian Stage Based on Foraminifers, *Voprosy Mikropaleontol.*, 1973, no. 16, pp. 3 - 35.

Lipina, O.A. and Reitlinger, E.A. Stratigraphie Zonale et Paleozoogeogrphie du Carbonifere Inferieur d'apres les Foraminiferes, *C.R. VI Congr. Inter. Stratigr. Geol. Carbon.*, Sheffield, 1970, vol. 3, pp. 1101 - 1112.

Makhlina, M.Kh. and Shik, E.M., Concept of Stratigraphic Scale of Carboniferous Deposits of Moscow Depression, *Geologiya i Poleznye Iskopaemye Tsentral'nykh Raionov Vostochnoevropeiskoi Platformy* (Geology and Mineral Resources of Central Regions of East European Platform), Moscow: Nauka, 1986, pp. 18 - 29.

Makhlina, M.Kh. and Zhulitova, V.E., Detailed Subdivision of the Tula Horizon in Its Stratotype Area, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1984, no. 12, pp. 3 - 11.

Putevoditel' Ekskursii po Razrezam Karbona Podmoskovnogo Basseina (Guidebook of Excursions to Carboniferous Sequences of the Moscow Basin), *VIII Int. Geological Congr. on Carboniferous Stratigraphy and Geology*, Moscow: Nauka, 1975.

Rauser-Chernousova, D.M., Stratigraphy of the Visean Stage of Southern Part of Moscow Basin Based on Foraminifers, *Trudy Inst. Geol. Nauk*, 1948, no. 62. pp. 3 - 40.

Resheniya Mezhvedomstvennogo Regional'nogo Stratigraficheskogo Soveshchaniya po Srednemu i Verkhnemu Paleozoyu Russkoi Platformy (Resolutions of Interdepartmental Stratigraphic Conference on Middle and Upper Paleozoic of Russian Platform, VSEGEI, 1988), Leningrad: VSEGEI, 1990.

Resheniya Mezhvedomstvennogo Soveshchaniya po Razrabotke Unifitsirovannykh Skhem Verkhnego Dokembriya i Paleozoya Russkoi Platformy (Resolutions of Interdepartmental Conference on Development of Unified Stratigraphic Scales of Upper Precambrian and Paleozoic of Russian Platform, VSEGEI, 1962), Leningrad: VSEGEI, 1965.

Stratigraficheskii Kodeks SSSR (Stratigraphic Codex of the USSR), Leningrad: Nedra, 1977.

Vdovenko, M.V., *Vizeiskii Yarus. Zonal'noe Raschlenenie i Paleozoogeograficheskoe Raionirovanie (po Foraminiferam)* (The Visean Stage. Zonal Subdivision and Paleozoogeographic Regions: Based on Foraminifers), Kiev: Naukova Dumka, 1980.

Vdovenko, M.V., Zonal Foraminiferal Scale of the Lower Carboniferous of Eastern Part of the East European Platform, *Dokl. Akad. Nauk Ukr., Ser. B: Geol., Khim., Biol. Nauki*, 1988, no. 9, pp. 10 - 14.

Vdovenko, M.V., Solovieva, M.N., and Bensh, F.R., Foraminiferal Zonal Scale of the Carboniferous, *Zonal'naya Stratigrafiya po Mikroorganizmam i Metody Ee Razrabotki* (Zonal Stratigraphy Based on Microorganisms and Methods of Its Development), Leningrad: VNIGRI, 1986, pp. 52 - 54.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 249 - 263. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 51 - 66.
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Paleogeography and Depositional Environment of the Triassic Sediments in the Caspian Sea Region

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Abstract – The Triassic depositional environment and paleogeography of Mangyshlak, Ustyurt, Eastern Ciscaucasia, and the Caspian Sea depression are considered in detail using lithological and biostratigraphic data. Main geological events of the Triassic are reconstructed, and the evolution of the sedimentary basin in the Caspian Sea region of that time is analyzed. Lithologic and paleogeographic maps are compiled for the Early (Olenekian Stage), Middle, and Late Triassic.

Main features of the Triassic paleogeography of the Caspian Sea depression, Ustyurt, eastern Ciscaucasia, and Mangyshlak have been considered in a series of works (*Atlas* ..., 1969; Movshovich, 1970; Savelieva, 1978; Lipatova *et al.*, 1982; Florenskii, 1982; Kukhtinov, 1984; Nazarevich *et al.*, 1984; Zhidovinov, 1985; *Atlas* ..., 1990; Yapaskurt, 1991). I considered them further in more detail on the basis of available lithological and biostratigraphic data, as well as on the interregional correlation of the Triassic deposits (Zhidovinov, 1993). For instance, some local stratigraphic units of the Caspian Sea depression, Ustyurt, and Mangyshlak (the table) were shown to be, according to their charophyte and conchostracan assemblages, synchronous and correlative to the upper part of the Kuma Formation and the lower subformation of the Neftekumsk Formation of eastern Ciscaucasia, both bearing remains of Lower Triassic bivalves and flora (Savelieva, 1978; *Reshenie* ..., 1979). The Olenekian deposits are correlated in accordance with data on the assemblages of Ammonoidea, bivalves, conchostracans, charophytes, and ostracods. The upper subformation of the Neftekumsk Formation, along with the Kultaiskaya and Dem'yanovskaya formations, and the lower subformation of the Kizlyarskii Formation of the eastern Ciscaucasia were correlated with upper parts of the Dolnapa and Amanbulak formations, and with the Tartali, Karadzhatyk, and Karaduan formations of Mangyshlak. In the Caspian depression, they correlate to the Baskunchak Group, Zhulidovskaya and Akzharsai formations, as well as to the Buzachi and Araldy formations of the Ustyurt. The correlation of the Middle Triassic deposits of the region was realized using remains of bivalves, gastropods, conchostracans, ostracods, and charophytes. The upper subformation of the Kizlyarskii Formation and the Novokolodeznaya Formation of the eastern Ciscaucasia are correlated with the Khozbulak, Aktas, Tenge, and Tasbulat formations, and also with the Temir Baba and Aksu Kendyrli Group of the Mangyshlak. In the Caspian depression, they are coeval with the Tsarynskaya, El'ton, Inder, Kiil, Tasshii, Sarpinskaya, and Masteksai formations, whereas in the Ustyurt their analogs are the Kalamkas, Arystan, Zhaiylgan, and Zapadnyi Chumyshty formations. Such units as Zakumskaya, Nogaiskaya, and Zurmutinskaya formations of the Eastern Ciscaucasia, the Shair and Auzar Formations, and Korzhaus Group of Mangyshlak, the Akmamuk, Khobda, and Kusankuduk formations of the Caspian depressions, and finally the Ashchitaipak Group of the Ustyurt are defined as the Upper Triassic on the basis of the bivalve, foraminifera, and miospore assemblages.

For the area under consideration, one may speculate on the events at the Paleozoic–Mesozoic boundary using only indirect data. In southern Mangyshlak, only the Olenekian deposits were well recovered by drilling, whereas the older Triassic sediments are poorly studied. In the Mangyshlak mountains, the Permian–Triassic boundary is controversial, and I place it conventionally at the base of the Dolnapa Formation. For the Ustyurt, the age of rocks underlying the Olenekian deposits is insufficieantly substantiated. In Eastern Ciscaucasia, the Permian–Triassic boundary is ambiguously interpreted as well, and I suggest its position to be at the base of the siltstone-mudstone member of the Kuma Formation. The lower boundary of the Triassic is more definite in the Caspian Sea depression, being marked here by the transition from red mudstone beds, containing Late Tatarian ostracods, to variegated sandstones with mudstone interlayers, comprising the Lower Triassic assemblages of ostracods and charophytes (Lipatova *et al.*, 1982). However, it appears difficult to trace it everywhere in this region.

Thus, to understand the paleogeographic environments in the Triassic, we have reliable information only since the Olenekian Stage. For the earlier interval, i.e., for the Indian (?) age, it is possible to suggest the following.

The larger part of the area under consideration was characterized mainly by a continental regime inherited

Correlation of the Triassic deposits in the Caspian Sea region

from the Late Permian. In the Caspian depression, thick polymineral sequences accumulated at that time under arid climatic conditions. The mountain ranges of the Urals and Mugodzhary in the east, the Voronezh Massif in the northwest, and the Karpinskii swell along with the South Emba uplift in the south served as source areas for the clastic material. The different composition of the mineral associations and patterns of the clastic material distribution over the area prove that various source regions existed (Lipatova *et al.*, 1982).

The clastic material was derived mainly from the southern spurs of the Urals and Mugodzhary, where intensive and predominantly mechanical destruction of metamorphic and igneous rocks occurred. This is confirmed by the composition of pebbles (conglomerates of the Blaktykul', Sorkul', and Kok Zhide formations), which were transported by rivers and temporary flows onto the alluvial plain occupying the eastern and southeastern parts of the territory. Fragments of sedimentary rocks the South Emba uplift were also transported here.

In the Caspian Sea depression, the coarse clastic deposits are replaced by clays and siltstones westward, the latter covering nearly all the area of this part of the depression. The consistent composition of the rocks, and, principally, the presence of ostracods, charophytes, and more rarely conchostracans in the rocks suggest the existence of reshened-water basin of a continental type (at least, in the central part of the territory). Muds, clays, and fine-grained sands were deposited in it. The well-sorted material, along with wavy and horizontal bedding of these deposits indicate calm hydrodynamic conditions with a wave regime that dominated the currents. The water mass was more dynamic at the northern, western, and southwestern margins of the depression, where siltstones and sandy deposits accumulated.

South of the Caspian Sea depression, a marine basin existed during the Indian (?). The deepest part of the basin occupied the territory of eastern Ciscaucasia (within an area of both the eastern Manych and Arzgir depressions, and the Velichaevsk–Maksimokumsk uplift). Its shallow coastal zones were in the western regions of the Mangyshlak mountains and the Buzachi arch.

The main provenances of Eastern Ciscaucasia were the Karpinskii swell in the north and the Stavropol' arch in the west. Their role as sources of sediments diminished through time. This is evidenced by sections of the Kuma Formation upper member (mudstone with interlayers of siltstone and sandstone), and the lower subformation of the Neftekumsk Formation (limestone, dolomite, and mudstone). Judging by the rock structure, the sedimentation occurred under calm hydrodynamic conditions and a warm, sometimes arid, climate. The sea water salinity seems to have been lower than normal. This is confirmed by the lack of cephalopods but a presence of marine stenohaline bivalves (mostly, the genera *Eumorphotis* and *Clarai*) in the section. The latter were byssus-sessile, prefering the lower sublittoral (Kurushin, 1990), or more rarely the pseudoabyssal depth ranges (150 - 200 m). In the latest Indian (?), the basin became shallower, which resulted in a partial erosion of the sediments (the upper part of the Kuma Formation), especially in the southeastern Ciscaucasia.

During the Indian (?), most of the Ustyurt and Mangyshlak territory was a land with an arid climate where clayey-silty psammitic sediments accumulated. The main provenances were the South Emba uplift in the north and the Kara Bogaz arch in the south. Similar deposits (the lower subformation of the Dolnapa Formation and the North Buzachi Formation) were also formed in the coastal shallow-water zone of the basin in the western part of the territory. The well sorted material and the high value of the ferric to ferrous iron ratio (>1) in the sediments indicate that they were deposited in an active oxidizing media. Ripple and wavy marks and desiccation cracks suggest a shallow depth.

The existence of two isolated basins of the Indian (?) (the continental in the north and the marine in the south) within the region under consideration suggest watershed area between them in the form of two connected elevated paleostructures: the Karpinskii swell and the South Emba uplift. This inference resulted from the following: (1) the presence of marine bivalve remnants in the Indian (?) sections of eastern Ciscaucasia, which were not encountered in coeval sediments of the Caspian Sea depression; and (2) the similar (if not identical) compositions of the Astrakhan' and Guriev terrigenous-mineralogic provinces (Lipatova *et al*, 1982), which indicates the same provenance (the Karpinskii swell and South Emba uplift). The lack of a watershed area would have undoubtedly caused either the fresh water ingression into the marine basin, if the Caspian Sea depression was at a higher level, or (on the contrary) sea transgression into the Caspian Sea depression.

In the Early Olenekian, the paleogeography did not change; the same provenances and sedimentation basins had configurations similar to those in the Indian (?). The entire territory of the Caspian Sea depression started sinking at the Early Olenekian, which resulted in a permanent water-mass exchange with the Tethys Ocean located south of it. As a consequence, normal marine conditions formed within eastern Ciscaucasia.[1] The hydrodynamic regime was calm at that time, and the depth was shallow, not more than 100 m (as is indicated by bivalves of the *Leptochondria*, and *Neoschizodus* genera), favorable for a dominantly carbonate sedimentation. In the western part of the Mangyshlak Mountains, the water level rose and the shoal turned into a small bay with mainly terrigenous sedimentation, where carbonate deposits accumulated only in the Latest Olenekian (the Shetpe beds). Bivalves (genera *Leptochondria, Eumorphotis*, and *Mytilus*), that inhabited the bay indicate variable hydrodynamics (from moderate to storm conditions) and a shallow depth, up to 50 m. On the remaining territory of Mangyshlak and Ustyurt, the depositional environ-

[1] This is implied by Ammonoidea remnants in the upper subformation of the Neftekumsk and Kultai formations (*Reshenie* ..., 1979).

ments were continental as before, and only on the Buzachi arch did a shoal with terrigenous sedimentation exist (the lower (?) subformation of the Buzachi Formation).

Within the Caspian Sea depression, continental sedimentation also was still progressing: thick layers of sandy-clayey sediments (the lower parts of the Zhulidovskaya and Akzharsai formations) were deposited there. However, the growing subsidence of the territory and a rise in the sea level in the basin located to the south caused sea ingression into the southwestern part of the depression through the submerged portion of the watershed. This is marked by single intercalations of bluish-green clayey siltstones occurring in the lower part of the Baskunchak Group, which contain the remains of stenohaline bivalves of the *Bakevellia* genus. According to Kurushin's (1990) investigations, the latter were byssus-sessile and preferred sandy-clayey grounds, moderately weak hydrodynamic conditions, and a depth of up to 50 m.

In the Late Olenekian, the transgression expanded as a result of the consequent subsidence of the territory, and the sea level rose due to inflow of water from the Tethys. Sea waters prograded further into the Mangyshlak and Ustyurt, covering nearly the entire southwestern part of the Caspian Sea depression. That is, by that time the watershed in the form of "the Karpinskii swell + South Emba uplift" ceased to exist, and a united sea basin was formed within the Caspian region (Fig. 1).

In eastern Ciscaucasia, the basin was bordered by the Karpinskii swell to the north, and by the Stepnoye, Ozeksaut, and other paleoridges to the south. By that time, a considerable peneplanation of the ancient land had already occurred, and sedimentary deposits were mostly eroded. The wave activity seems to have taken the leading role in the transportation of pelite material, as basin hydrodynamics were low or moderate judging by the bivalve remains of *Eumorphotis, Bakevellia, Unionites, Neoschizodus,* and *Leptochondria* genera. These remains also indicate variation in basin paleodepths (from $\simeq$100 to $\simeq$20 m). Greater depths existed in the eastern Manych depression and central parts of the Arzghir and Chograi depressions. Further to the south, the sea depth decreased about twice within the Vladimir depression and Talovaya tectonic terrace. The dark-gray, almost black color of the clayey and clayey-carbonate deposits (the Dem'yanovskay Formation), which bear abundant pyrite, indicates reducing conditions. Judging by the numerous Ammonoidea remains, the sea water salinity was normal.

In the Mangyshlak area the deepest depths were in the western part (the Karatauchik Range, Western Karatau), as well as in southern Mangyshlak. Mostly calcareous ooze and mud (the Tartali and Karadzhatyk formations) were formed in these regions. Judging by the bivalve remains of the *Unionites, Neoschizodus, Myalina, Leptochondria, Eumorphotis,* and *Bakevellia* genera, this region of the sea basin was characterized by an intensive hydrodynamics, a depth of 50 m, and good water aeration. A shoal zone was situated in the east (the western part of the East Karatau Range), where clayey and sandy deposits accumulated (the mudstone-siltstone sequence of the East Karatau Group). Rarely occurring bivalves of genus *Unionites*, which preferred sandy grounds, indicate intensive hydrodynamics and good water aeration. It seems that the depth did not exceed 20 m. In southeastern Mangyshlak, a coarser material was deposited, indicating the proximity of a provenance. Traces of digging organisms and the presence of limonite in mineral grains indicate a shoal with reducing conditions. A similar depositional environment existed in southern Mangyshlak, where siltstone and mixed clayey-siliceous sediments with an admixture of tuffaceous material derived from adjacent volcanoes (the Fetisovo Formation) accumulated. Sandy sedimentation was of subordinate importance here.

The Buzachi arch area and the western part of the North Ustyurt depression were a shoal zone. Its shallow-water environments are evident from desiccation cracks, traces of turbidity and rewashing in the clayey-silty sediments (the Buzachi and Araldy formations), and caverns left by digging organisms. Eastward, the basin was replaced by a coastal plain flooded at times by the sea. This inference was made on the basis of sediment composition and the abundance of eurybiontic ostracods and charophytes remains. Depositional environments were extremely oxidizing.

In the Caspian Sea depression, the Late Olenekian marine depositional environments existed only in its southwestern part and the southern Ural–Volga interfluve area. Bivalves of the *Bakevellia, Leptochondria, Myalina, Mytilus, Neoschizodus, Myophoriopis*, and *Unionites* genera indicate a range of 20 - 50 m depth in the basin, and moderate to intensive hydrodynamics. In the southwestern part of the basin, variegated terrigenous deposits accumulated under the normal redox potential during the initial stage of transgression, and later gray mud and carbonate ooze were deposited under reducing conditions (the Baskunchak Group). Within the southern Ural–Volga interfluve area, only sandy-clay deposits (the Zhanatalap Group) were formed. The rocks of the South Emba uplift, Karpinskii swell, and Voronezh anteclise most likely served as provenances. The well sorted material and presence of carbonates attests that chemical weathering dominated over the mechanical desintegration there. The Th/U ratio below 7 also points to a deep chemical reworking of host rocks and to the transportation of radioactive elements in dissolved form (Kovalev, 1965). The normal salinity regime lasted for a short period of time, during the *Dorikranites*, and *Tirolites* zonal intervals only. Later, judging by fossils, the basin freshened in part due to a substantial inflow of river waters. I.A. Efremov related the redeposited remains of Labirinthodontia amphibian *Parotosaurus, Inflectasaurus*, and *Trematosaurus* in the coastal area to the activity of fresh-water flows. The change in salinity resulted in a complete disappearance of Cephalopoda and in stunted forms of bivalve mollusks. The representatives of the

Mytilus, *Bakevellia*, *Parallelodon*, and *Gervillia* genera, which evolved in abundance under the normal salinity, were replaced. When the freshening of the basin started, the euryhaline *Myalina*, and *Unionites* forms, which are able to survive under turbulent hydrodynamic conditions and shallow depth (up to 20 m), became dominant.

Throughout the rest of the Caspian Sea depression, continental sedimentation occurred in coastal and alluvial plains. Within these plains, small continental basins, populated with abundant ostracods and charophytes, seem to have existed. Sedimentation was solely terrigenous (the Zhulidovskaya and Akzharsai formations and the Caspian Group), supplied with clastic material from the Mugodzhary, Urals, and South Emba uplifts.

At the end of the Early Triassic, the upward movements within the Kara Bogaz arch[2] disrupted connections with the Tethys Ocean and converted the Late Olenekian basin of the Caspian Sea region into an inner sea. This event is confirmed by the lack of Ammonoidea above the *Stacheites* beds in the Triassic sections of eastern Ciscaucasia, Mangyshlak Mountains and the northern part of southern Mangyshlak, as well as above the *Tirolites* beds in localities of the southwestern sector of the Caspian Sea depression, and higher than the *Columbites* level in southern sequences of the southern Mangyshlak. The spatial discordance in these stratigraphic levels, seemingly the result of a gradual freshening of the sea basin (Verzilin, 1979), that was initiated in restricted areas did not change the depositional environments but rather led to a disappearance of Ammonoidea. So, the clay-carbonate sedimentation (the lower subformation of the Kizlyarskii Formation) progressed in eastern Ciscaucasia until the end of the Early Triassic. Remains of bivalves of the *Unionites*, *Neoschizodus*, and *Myophoriopis* genera, characterized by moderate hydrodynamic activity and a depth of 20 - 50 m, confirm the preservation of former conditions in the basin (except salinity). A similar situation existed in the western part of the Mangyshlak mountains, where sandy-clayey and more rarely carbonate (the Karaduan Formation) deposits formed.

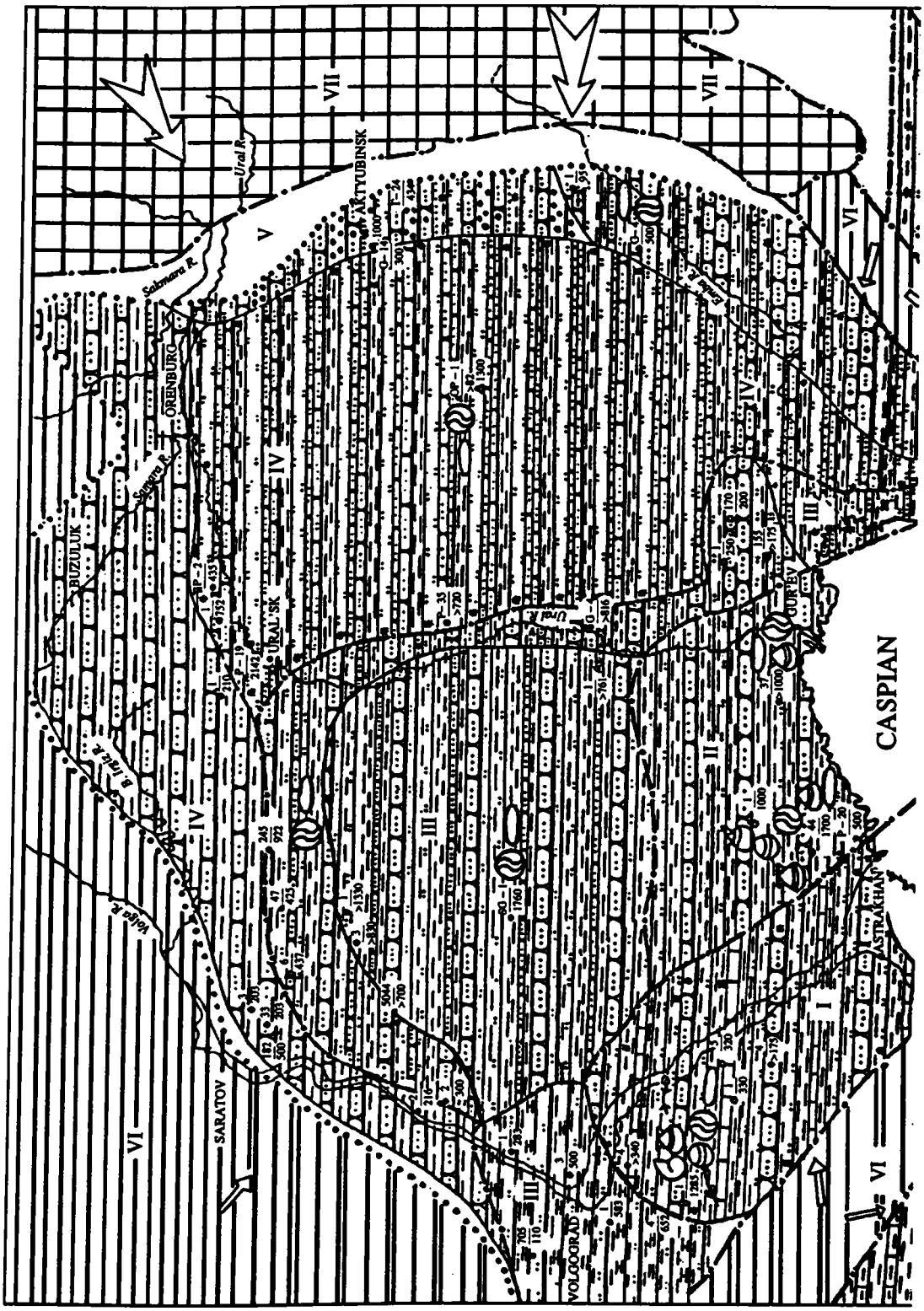
Thus, in the Middle Triassic the isolated brackish-water basin covered the largest part of the territory under consideration. It was populated with marine bivalves, but barren of Cephalopoda. The basin was considerably expanded as compared to that of the Late Olenekian, indicating a more extensive tectonic subsidence of the territory. All the main provenances of the Early Triassic were preserved through the Middle Triassic (Fig. 2).

Biogenic, and to a lesser extent terrigenous sediments alternating with volcanosedimentary deposits (the Khozbulak Formation) accumulated during the Middle Triassic within the western part of the Mangyshlak Mountains (the Western Karatau range). Highly weathered chlorite, mica, feldspar, and shale fragments, which occur as the clastic components together with fresh volcanic clasts, indicate the increased role of chemical weathering of the provenance rocks at the initial stage of climate humidization. In eastern regions (the East Karatau range), the role of terrigenous sedimentation was more substantial near to the provenances. Tuffstone and tuff were deposited everywhere during the periods of intensified volcanic activity.

Numerous species of bivalve and gastropod mollusks, together with more rare ostracodes, and abundant algae inhabited the Mangyshlak Mountains of the Middle Triassic basin. A depth up to 50 m and moderate hydrodynamic conditions were typical of the western region of the Mangyshlak Mountains, which is indicated by the prevalence of bivalves of the *Myophoriopis*, *Unionites*, *Neoschizodus*, and *Mytilus* genera. The eastern areas, located closer to the shore line, were characterized by a shallower depth, up to 20 m, and turbulent water hydrodynamics. This is inferred from the bivalve assemblages comprising mainly the representatives of genus *Unionites*. The lack of bivalve remains in the upper subformation of the Khozbulak Formation, as well as in the overlying lower subformation of the Shair Formation of the eastern Karatau Range, could be related to significant environmental changes in this part of the basin, which occurred at the Middle-Late Triassic boundary: either by further freshening of the sea water, or by a brief fall in the sea level. A gradual decrease in the taxonomic diversity of nearly all the fauna groups of the Middle Triassic favors water freshening.

In general, the Middle Triassic sedimentation in southern Mangyshlak was similar to that in the Mangyshlak Mountains. In northern areas, more distant from the provenances, the carbonate ooze with rare interlayers of terrigenous deposits accumulated. Southward, approaching the Kara Bogaz arch that served as a provenance, the grain size of deposited material grew in contrast to the decreasing share of carbonates. By the terminal Middle Triassic, in southern Mangyshlak, the carbonate sedimentation was replaced by a deposition of terrigenous material, distinguishing this province from the mountain area of the region. At the beginning of the epoch, the carbonate sedimentation, which is characterized by an insignificant supply of terrigenous material (the Aktas Formation), dominated the main part of the territory. Only in the south, near the provenances, did carbonate and terrigenous sediments accumulate in equal proportions, having an admixture of volcanic material (the Aksu–Kendyrli Series). By the Middle Triassic, the carbonate sedimentation still dominated in the basin, but had a substantially higher share of terrigenous material (especially in southern and southeastern areas). Tuffaceous components became more important in sedimentation processes. Carbonate, more rarely clayey sediments (the Tenge Formation) accumulated in the northern areas of southern Mangyshlak. Southward, they were mainly replaced by terrigenous sediments and volcanic rocks (the lower part of the Temir

[2] In the core of the Tuarkyr anticline, the Lower Triassic deposits lie with a sharp angular unconformity on the rocks containing remains of the Late Olenekian Ammonoidea (Astakhova, 1973).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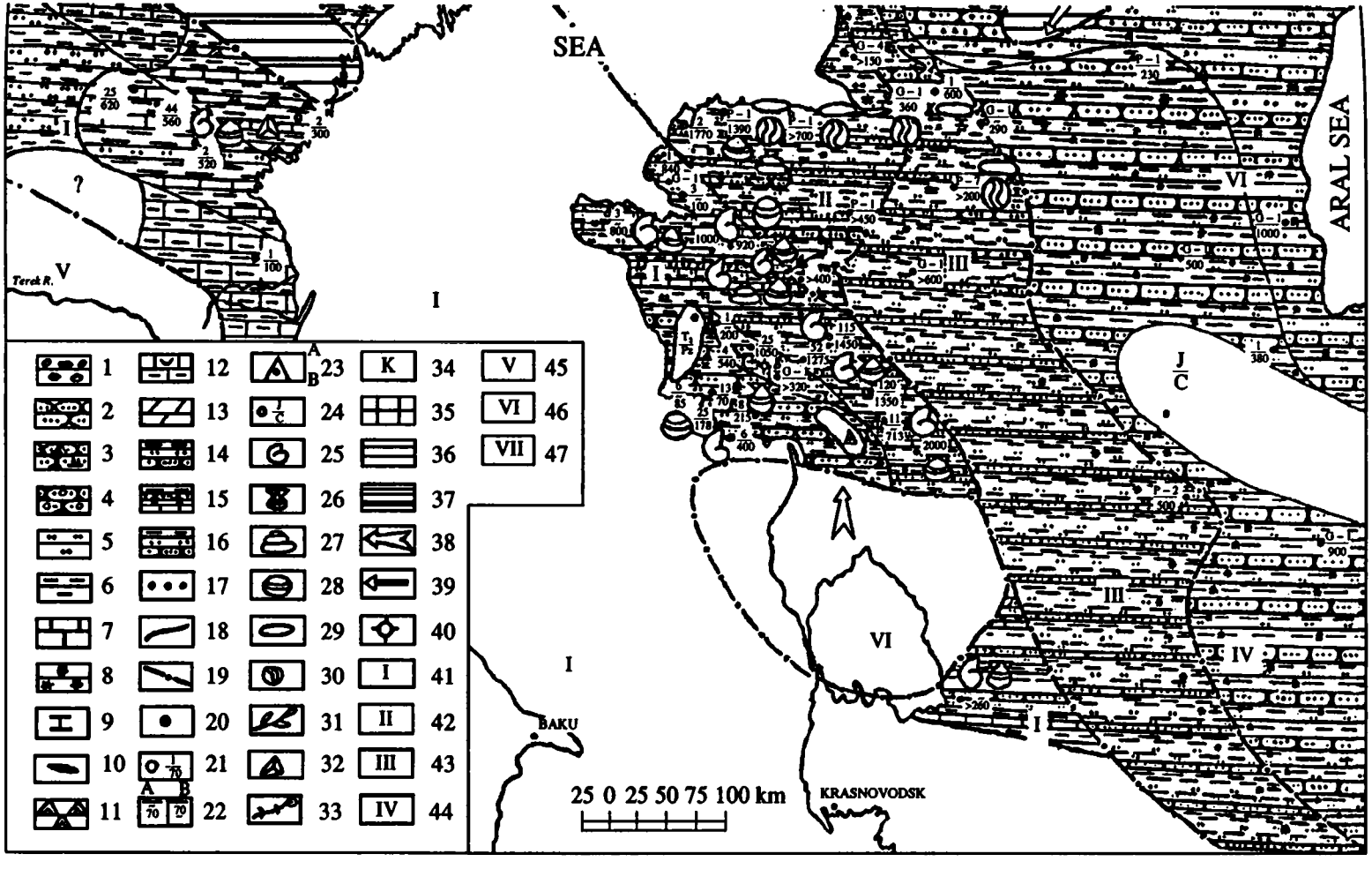
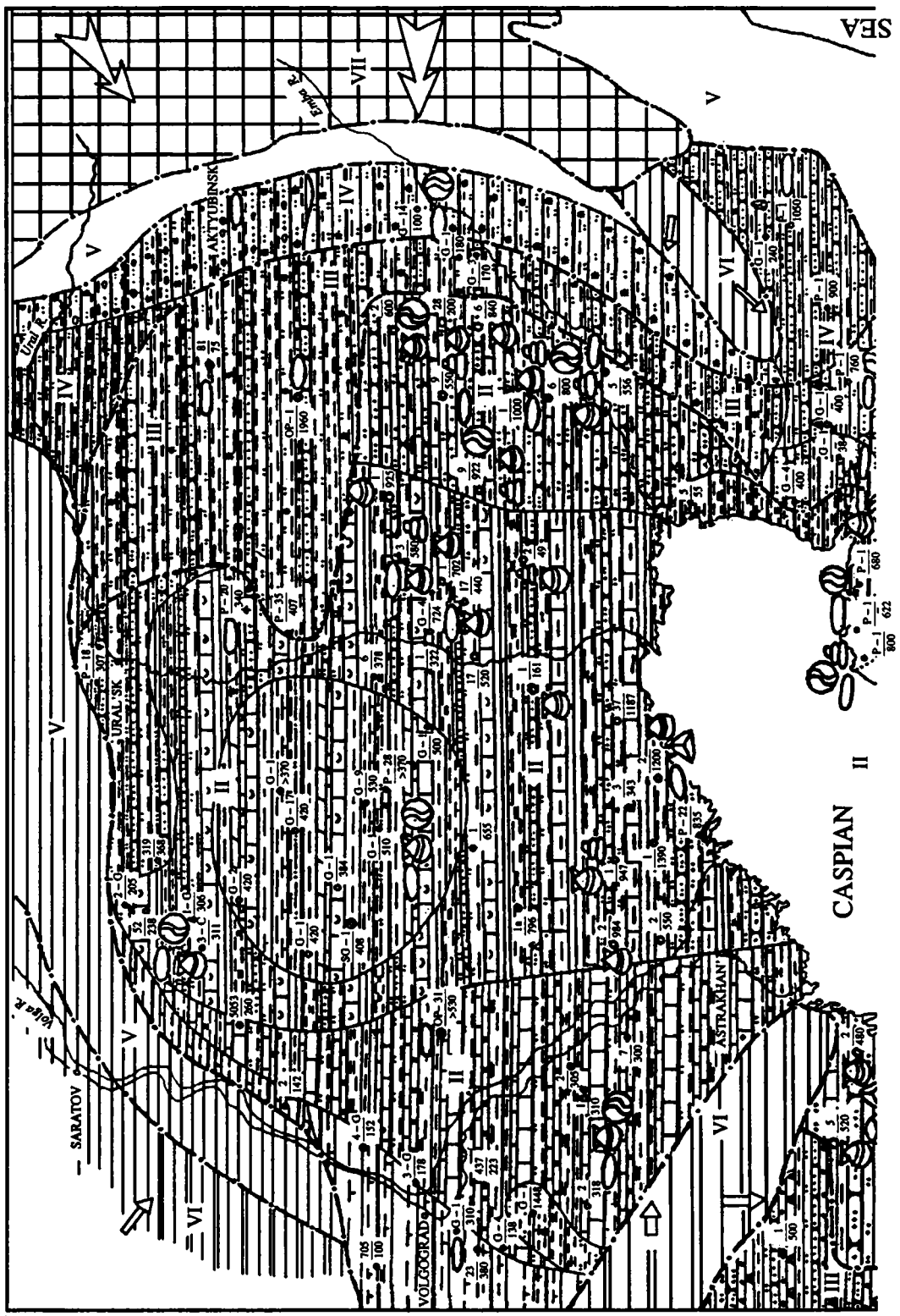


Fig. 1. Schematic litho-paleogeographic map of the Caspian Sea region for the Early Triassic (Olenekian Stage).

Lithological complexes: 1 – shingle beds, conglomerates; 2 – sandstone; 3 – tuffstone (A), sandstone with dolomite matrix (B); 4 – sandstone with gravel, pebble; 5 – siltstone; 6 – mudstone; 7 – limestone; 8 – originally red beds; 9 – lime-containing beds; 10 – coal; 11 – tuff; 12 – limestones, organogenic (A) and clayey (B); 13 – dolomite; 14 – thin interbedding of mudstone, siltstone, and sandstone; 15 – thin interbedding of mudstone, sandstone, siltstone, and limestone; 16 – schematic section in a natural succession. Boundaries of: 17 – ancient erosion; 18 – lithologic complexes; 19 – paleogeographic areas; 20 – exposure; 21 – borehole, its number/thickness; 22 – incomplete thickness: no data on the upper part of the section (A), no data on the lower part of the section (B); 23 – seismic data; 24 – no deposits of given age. Organic remains of: 25 – Ammonoidea, 26 – bivalves, 27 – gastropods, 28 – conchostracans; 29 – ostracods; 30 – charophytes; 31 – flora; 32 – miospores; 33 – vertebrates; 34 – kaolinite. Rocks of provenances: 35 – effusive and metamorphic; 36 – sedimentary, 37 – carbonate. Direction of clastic material drift: 38 – principal; 39 – minor; 40 – fissure volcanoes. Paleogeographic regions: 41 – sea, shallow part of shelf; 42 – sea, offshore part; 43 – coastal plain flooded by sea at times; 44 – low alluvial plain; 45 – high plain, plateau; 47 – mountains.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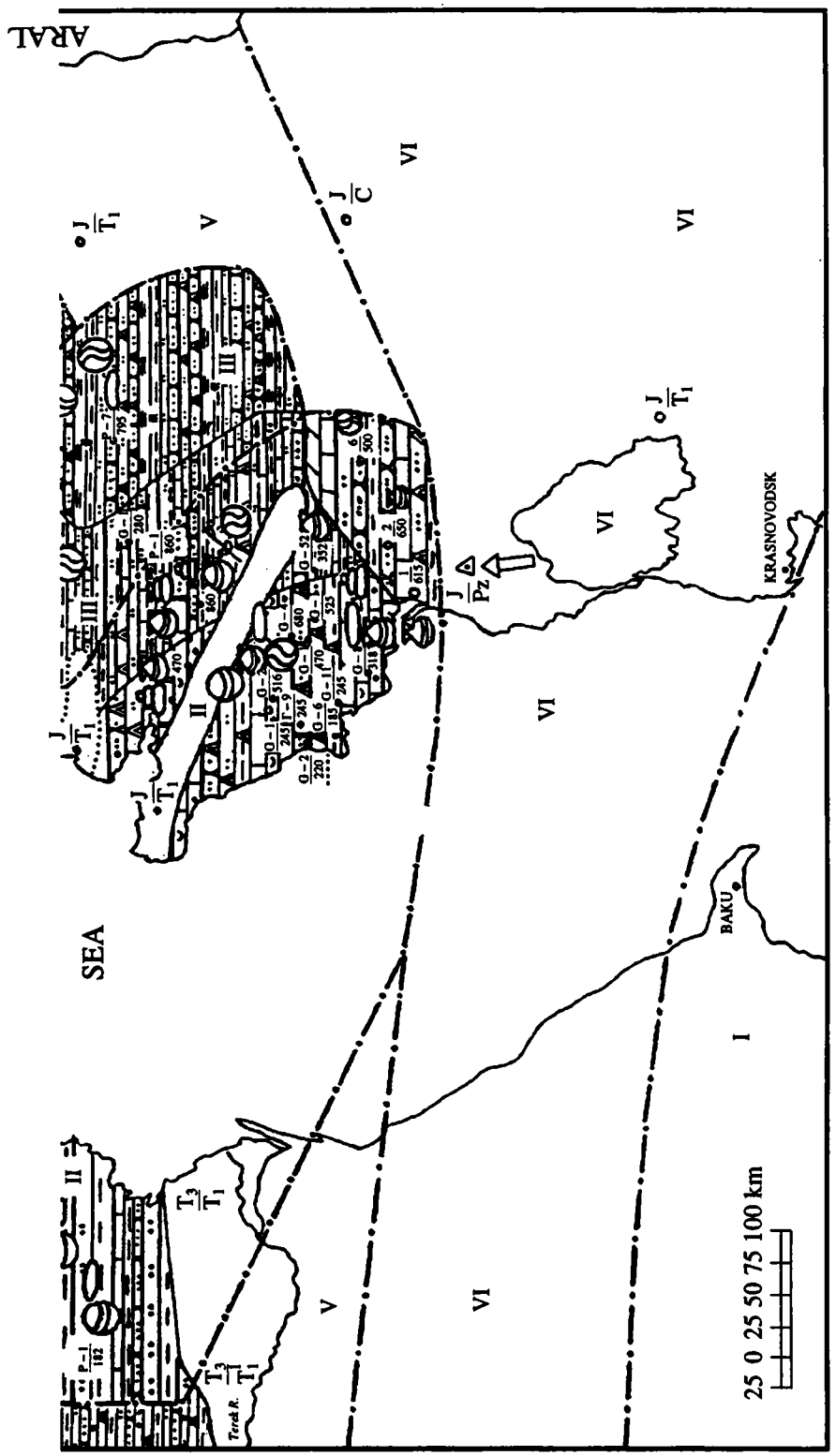


Fig. 2. Schematic litho-paleogeographic map of the Caspian Sea region for the Middle Triassic. See Fig. 1 for the legend.

Baba Group). Beginning at the second half of the Middle Triassic, the basin depth became shallow, giving rise to an insular sea.[3] The carbonate sedimentation was completely replaced by terrigenous, and the basin water became almost completely fresh, as indicated by its Sr/Ba coefficient (less than 1). Only in some places of the basin bays (the southern part of the southern Mangyshlak) were conditions suitable for marine bivalves (genus *Myophoriopis*) and carbonate deposition (the upper parts of the Temir Baba Group) still retained. On the rest territory of southern Mangyshlak, clayey, silty-clayey, and psammitic sequences with a great amount of tuffaceous material (the Tasbulat Formation) were formed. The presence of coalified plant remains and calcite microconcretions suggests that in some cases the sediments also accumulated in a subaerial environment. In general, the decayed organic matter generated the reducing conditions.

Throughout the existence of the southern Mangyshlak sea basin, its depth did not change (about 30 to 50 m). The same can be said for the hydrodynamics, which were moderate to intensive. This is confirmed by bivalve remains of the *Unionites* and *Myophoriopis* genera encountered at nearly all stratigraphic levels. Their absence in the lower half of the Temir Baba Group seems indicative of a short-term freshening (or exsiccation) of this part of the basin located near the provenance, the Kara Bogaz arch.

When marine conditions predominated in the Mangyshlak territory, both the marine and continental environments coexisted in Ustyurt. A coastal shallow-water zone in the Middle Triassic sea basin occupied the northern areas of the Buzachi arch, where carbonate-terrigenous sedimentation was in progress (the Kalamkas Formation). The material accumulated here varies from carbonate to terrigenous with a tuffaceous admixture. Sandy and mixed sandy-silty to clayey deposits with traces of ancient hypergene alterations that accumulated in the second half of the Middle Triassic indicate shoaling and the emergence of dry land. Eastward (the western part of the North Ustyurt depression), the marine environments changed into a coastal plain with carbonate-terrigenous, terrigenous, and volcanoterrigenous deposits of lacustrine-alluvial and lacustrine-deluvial origin (the Arystan and Zhaiylga formations). In contrast to the northern areas of the Buzachi arch, no differentiation of the sedimentary material is observed here; only mixed varieties of rocks dominate in the sections. In general, within the eastern part of the North Ustyurt depression, the continental, subaquatic, and subaerial deposits represented by mixed sandy-silty rocks (the Zapadnyi Chumyshty Formation), were formed. The effect of volcanic processes was minimal here.

Ostracods and charophytes inhabited the Middle Triassic basins (mainly fresh-water) of Ustyurt. Bivalves (genus *Unionites*) dwelt in the coastal shoal of the Buzachi arch, which was 20 m deep and had an active hydrodynamic regime.

In the Middle Triassic, sea waters covered all the Caspian Sea depression except its easternmost and northeastern areas. Its coastal zones mostly sand and silt accumulated whereas silty, clayey, and more rarely carbonate sediments were formed in the open sea basin (Fig. 2).

At the beginning of the transgression, the terrigenous sedimentation (the lower subformation of the El'ton Formation) dominated, and carbonate deposits (the lower subformation of the Tsarynskaya Formation) accumulated only in the southwestern part of the basin. The latter is a result of irregular sinking of the basin, giving rise to deeper sedimentation environments with a minimal supply of clastic material. By the end of El'tonian time, clayey-carbonate sedimentation (the upper subformation of the El'ton Formation) became dominant in the northwestern, western, and central parts of the basin. The change in the sedimentation type was related to the peneplanation of provenances and to erosion of their carbonate rocks, as well as to a sea level change. Sandy-clayey deposits of that time (the Oryzkazgan Formation) accumulated in the southeastern part of the basin, near the South Emba uplift (Lipatova *et al.*, 1991).

Regularities of the El'tonian sedimentogenesis were preserved later on: the sections of the Inder Formation display the same transition from terrigenous to clayey-carbonate sediments. The upward movements that occurred at the end of the Middle Triassic resulted in sea water regression, as well as in an increased supply of clayey, and then sandy-silty material (the Sarpinskaya and Masteksai formations). Marine conditions lasted for a longer period of time in the southern part of the Ural–Volga interfluve area, a fact confirmed by abundant bivalve remains (Lipatova *et al.*, 1992) lacking in other synchronous sections.

Judging by fossils (bivalves, gastropods, conchostracans, and ostracodes), the hydrologic regime of the Caspian part of the sea basin was stable through the Triassic. The basin depth did not exceed 50 m and hydrodynamics was moderate to intensive, i.e., conditions were similar to those in the Mangyshlak area. Bivalve remains of the *Unionites, Myophoriopis, Neoschizodus,* and other genera that were encountered at different stratigraphic levels of the Middle Triassic indicate that the sedimentation medium was reducing.

East of this sea basin, the territory of the Caspian Sea depression represented a coastal plain (sometimes flooded with sea water), which was later replaced by an alluvial plain with a well-developed river and lake system. Sandy-clayey to silty deposits accumulated in this plain, having the Urals as a provenance. In addition to the sediments mentioned, carbonate ooze accumulated during periods of marine conditions.[4] Clayey and silty, more rarely sandy, sediments (the Tasshyi

[3] Rare findings of bivalve remains of the *Unionites* genus in the lower subformation of the Tasbulat Formation indicate that marine environments still existed at that time.

[4] Bivalves of the *Unionites* genus occur in the upper subformation of the Kiil Formation.

Formation) were deposited in river valleys and lakes (Lipatova *et al.*, 1982).

In Eastern Ciscaucasia, the Middle Triassic sea basin retained the Late Olenekian configuration (Fig. 2). Clayey and sandy-silty sediments formed in this basin, the latter being characteristic of its western and northern parts closest to the provenances. The carbonate accumulation was subordinate in the basin.

At the beginning of the Middle Triassic, the accumulation of clayey, more rarely carbonate, sediments with a minimal input of silty-sandy material (the upper subformation of the Kizlyarskii Formation) dominated in calm depositional environments inherited from the Late Olenekian. Bivalve remains of the *Myophoriopis* and *Unionites* genera indicate a basin depth of 30 to 50 m and a moderate to intensive hydrodynamic regime during that time. Since the mid part of the Middle Triassic, the sea basin regime changed: the depth probably decreased to 20 m and the hydrodynamics intensified. This is inferred from bivalves of the *Neoschizodus* and *Unionites* genera, and from the character of sediments represented by poorly sorted, mostly clastic deposits with occasional carbonate beds (the Novokolodeznaya Formation). The shoaling of the basin resulted from the initiation of tectonic activity, which slightly uplifted the eastern Ciscaucasia together with the surrounding provenances. This corresponds well with manifested volcanic activity, especially within the East Manych and Arzghir depressions, where the Middle Triassic sections comprise tuff interlayers.

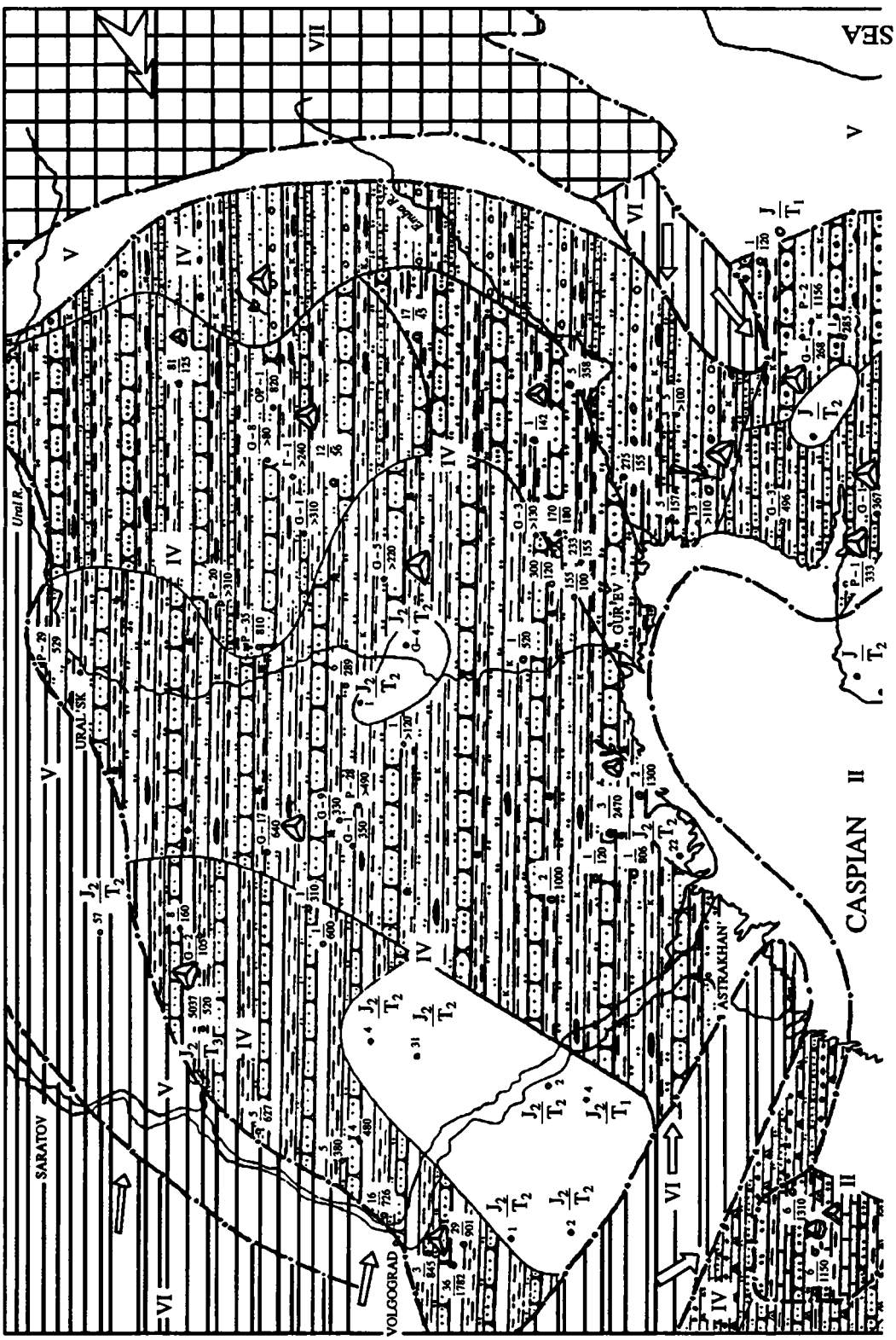
The Caspian region underwent uplifting at the Middle-Late Triassic boundary, which resulted in the regression of sea water back to the modern area of the Caspian Sea. In the Late Triassic, marine conditions occurred only within the Mangyshlak Mountains and eastern Ciscaucasia, on the rest of the region the regime was continental. This and an intensive pre-Jurassic erosion of the Triassic deposits complicated the paleogeographic reconstructions of the Late Triassic period, which are thus conventional (Fig. 3).

A vast alluvial plain with a well-developed lake-river system (temporary streams in its eastern part) existed in the Caspian Sea depression in the Late Triassic. Only terrigenous sedimentation occurred within this plain. Sandstones accumulated here in the earliest Akmamykian time, whereas gravel and pebble material was added to sandstones in the eastern and southeastern areas, indicating that the provenances experienced an increased uplift (the Urals and South Emba uplifts). Sandy material was mostly oligomictic, consisting of quartz, and only in the eastern areas was it polymictic. This type of sedimentation was replaced by an accumulation of clayey deposits since the second half of the Akmamykian time. The river bed and flood plain deposits together with the lacustrine and marsh sediments form a composite sedimentary cycle. The cycle base consists of cross-laminated sands and sandstones with interlayers of gravellite and conglomerate. This member is replaced by clays and siltstones with sandstone intercalations in marginal areas of the Caspian Sea depression. Calcareous clays, silts, and fine-grained sands, enriched in coalified plant remains, likely accumulated in lakes and marshes. In the Khobdian, and later in the Kusankudukian time, sedimentation was similar to that of the Akmamykian period: the alluvial sedimentation dominated at the beginning (deposition of silty-sandy material), and then was gradually replaced by lacustrine-marsh, i.e., more clayey sedimentation.

In eastern Ciscaucasia, the period of marine environments was short in the Late Triassic, probably corresponding only to the accumulation time of the Zakumskaya Formation. Remnants of bivalves of the *Mytilus* and *Unionites* genera indicate that sedimentation occurred at a small depth (not more than 20 m) and turbulent hydrodynamic conditions. At the beginning, there was a brief period of carbonate accumulation, then sandy-clayey sediments became dominant, reflecting the intensified denudation processes in the provenances (the Karpinskii and local paleoridges). Further uplift of the eastern Ciscaucasia region resulted in the replacement of marine sediments by continental deposits, as well as in a partial erosion of the sediments deposited. This corresponds to the fact that the Nogaiskaya Formation deposits overlap, with the angular unconformity, the underlying rocks.

The continental sedimentation occurred in the alluvial plains, accompanied by intense volcanic activity. Main volcanic centers were located within the Nogaiskaya terrace, Arzghir, Otkaznensk, Chernolessk, and Berezkino depressions (Savelieva, 1978). Thick lava flows of acidic and intermediate composition, as well as sequences of volcano-sedimentary deposits were formed as a result of the eruptions. Simultaneously, a coarse clastic material (the Nogaiskaya Formation), derived from the rising provenances, accumulated in huge amounts. At the end of the Late Triassic, the volcanic activity ceased giving place to sandy-clayey deposits (the Zurmutinskaya Formation).

In the Mangyshlak and Ustyurt areas, Late Triassic marine sedimentation, as a result of the basin regression, existed only within the limits of the modern Mangyshlak Mountains, as is evident from abundant bivalve remains of *Mytilus, Unionites, Myophoriopis*, and *Trigonodus* genera encountered in the Shair and Ausar formations. Like in eastern Ciscaucasia, it was a shallow-water (the depth not more that 20 m) sea bay with moderate to intensive hydrodynamics. Terrigenous sedimentation dominated in the bay; conditions favorable for accumulation of carbonate ooze and volcanic products (the Shair Formation) originated very rarely and for a short period of time. Rivers supplying it with clastic material had a calm hydrodynamic regime, as is seen from well-sorted terrigenous material. The input of the clastic material increased and interlayers of continental sediments (the Ausar Formation) appeared in the Latest Triassic deposits as a result uprising in the area. Judging by their composition, the sediments were formed at that time in the lacustrine-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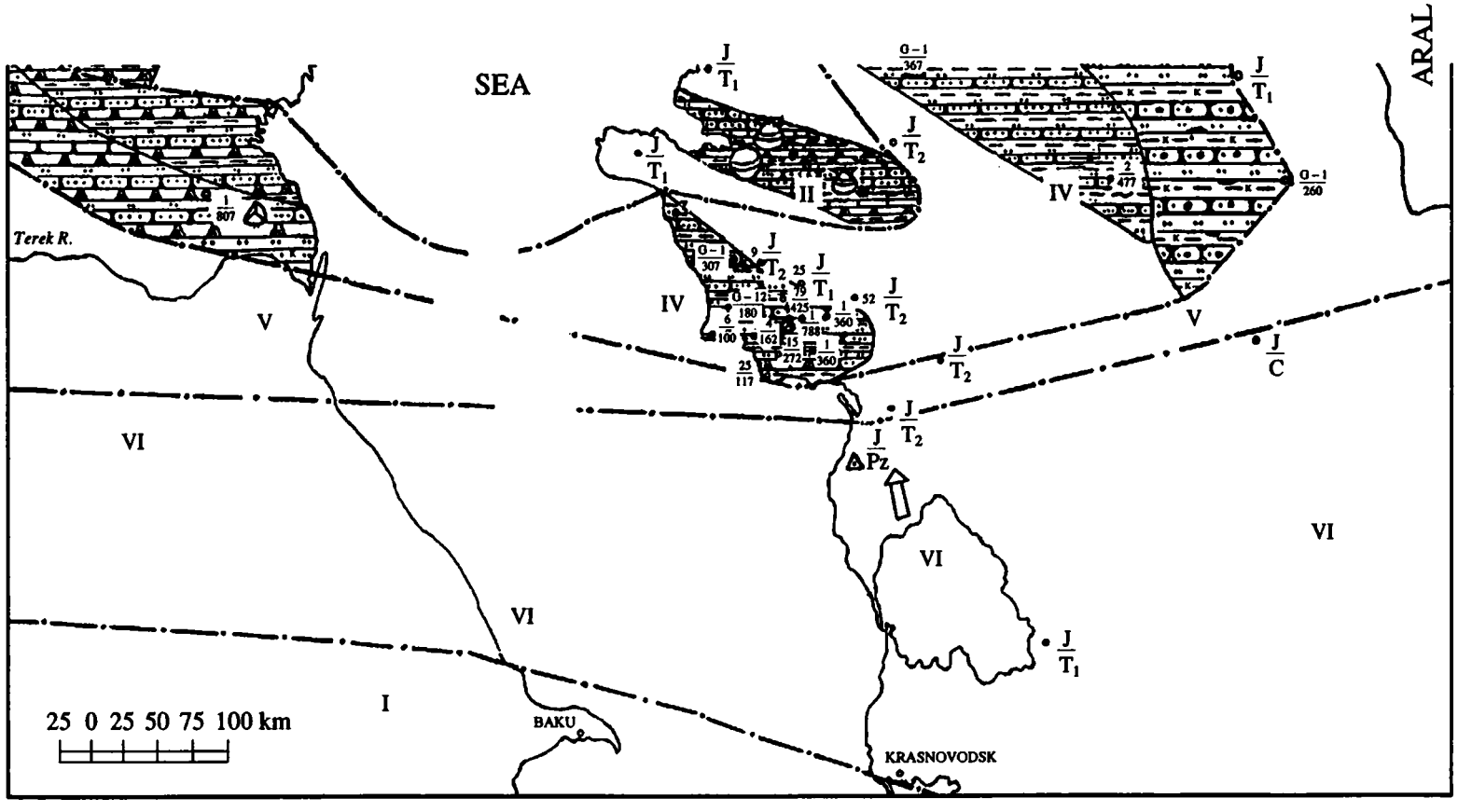

Fig. 3. Schematic litho-paleogeographic map of the Caspian Sea region for the Late Triassic. See Fig. 1 for the legend.

alluvial plain environments in prevailing reduction conditions.

The alluvial plain with a well-developed river system extended north, east, and south of the sea basin, a fact confirmed by numerous incisions visible on the seismic profiles. Within the larger part of the southern Mangyshlak area, the lacustrine-alluvial sedimentation occurred under redox conditions, and resulted in the accumulation of silty, clayey, and psammitic sediments with a tuffaceous admixture (the Korzhaus Group). In the second half of the Late Triassic, the volcanic material ceased to appear, and mostly silt deposits accumulated. Barite, pyrite, and siderite that occurred at this time indicate the reducing conditions. In the Late Triassic, denudation processes prevailed in the southern part of Mangyshlak as the Middle Triassic deposits of the area are mostly desintegrated.

Sand, gravel, silt, and clay (the Ashchitaipak Group) accumulated on the territory of the North Ustyurt depression. The weathering crusts on metamorphic and tuffaceous rocks underwent erosion on the watersheds. During transportation, the material was crushed, dissolved, and then converted into colloid form. Accordingly, the number of pelolithic and clay interlayers increased. Facies of the floodplain, lacustrine, and river bed alluvium alternating with subaerial sediments (including soils) indicate unstable depositional environments. The diagenetic redox reactions resulted in the appearance of coagula and concretions of siderite. The lake-type basins seem to have existed in the eastern areas of the depression, a fact confirmed by the mineral composition, structural, and chemical peculiarities of the rocks. In the Late Triassic the Buzachi arch served as a provenance, where the Middle Triassic deposits were mostly destroyed.

The aforesaid allows us to distinguish four major stages in the evolution of the sedimentation basin existing in the Caspian Sea region during the Triassic. The first stage covered the Indian time and was characterized by continental depositional environments, which were inherited from the Late Permian (except eastern Ciscaucasia, where marine conditions existed). In spite of the great similarity in the paleogeographic environments of the Late Permian and Early Triassic, the Mesozoic was a period that initiated downward tectonic movements. This is indicated by the Lower Triassic sequences of red terrigenous rocks in Western Kazakhstan, and the preservation of the marine conditions in eastern Ciscaucasia.

The second stage in the basin evolution embraces the Olenekian period of normal marine conditions, which began in the main part of the territory due to the water exchange with the Tethys Ocean. The Early Triassic climate of the Caspian Sea region was arid. This is confirmed by the polymictic character of terrigenous deposits, the prevalence of mechanically differentiated clastic material, and the insignificant content of coalified plant remains throughout the sections. The Olenekian transgression was responsible for the more humid climate in contrast to a warm and, periodically, even arid climate of the first stage.

The third stage is characterized by the onset of a brackish-water regime and a new sedimentation cycle, which continued through the Middle Triassic. At the Early-Middle Triassic boundary, the connection with the Tethys Ocean ceased, and the sea basin was converted into the inner sea, similar to the modern Caspian Sea. The sea covered the most of the territory, thus indicating the maximum points of tectonic sinking in the Caspian Sea region during this period of the Triassic. Such a spacious sea basin affected the climate, making it more humid. This is evident from a low proportion of polymictic material in the rocks, the result of a limited input of terrigenous material from the combined mechanical and chemical differentiation of the material, and from a higher amount of coalified plant remains (especially in the upper parts of the sections).

The fourth stage in the evolution of sedimentary basins corresponds to the Late Triassic and is characterized by the onset of continental depositional environments due to a general uplift of the Caspian Sea region. Marine conditions were preserved only within the Mangyshlak Mountains area and episodically in eastern Ciscaucasia. The sea regression and further increases in climate humidity resulted in flourishing plant vegetation, and at the end of the epoch even in the accumulation of coal. The climate humidity is confirmed by the high degree of rock alteration, the chemical differentiation of the material, and reducing conditions.

Reviewer A.A. Shevyrev.

REFERENCES

Astakhova, T.V., Tuarkyr, *Stratigrafiya SSSR. Triasovaya Sistema* (Stratigraphy of the USSR. Triassic System), Moscow: Nedra, 1973, pp. 199 - 202.

Atlas Litologo-Paleogeograficheskikh Kart SSSR. T. 3. Mezozoi. Triasovaya Sistema (Atlas of Lithologic-Paleogeographic Maps of the USSR. vol. 3. Mesozoic. Triassic System), Moscow: Nedra, 1969.

Atlas Paleogeograficheskikh Kart. Shel'fy Evraazii v Mezozoe i Kainozoe. T. 2. Kaspiiskoe More. Rannii Trias. Srednii Trias. Pozdnii Trias (Atlas of Paleogeographic Maps. Shelves of Eurasia in the Mesozoic and Cenozoic. vol. 2. The Caspian Sea. Early Triassic. Middle Triassic. Late Triassic), Robertson Group Pbl. Co., GIN Akad. Nauk SSSR, 1990.

Florenskii, P.V., Triassic Deposits of the Turanian Plate (Composition, Structure, Oil Resources), *Doctorate (Geol.) Dissertation*, Moscow: I.M. Gubkin MINKh i GP, 1982.

Kovalev, V.A., Geochemical Aspects of Investigations on Th/U Ratio in Sedimentary Rocks, *Geokhimiya*, 1965, no. 9, pp. 1171 - 1173.

Kukhtinov, D.A., The Upper Permian and the Triassic of the Aral-Caspian Region, *Doctorate (Geol.) Dissertation*, Leningrad: Vsesoyuzn. Geol. Inst. (VSEGEI), 1984.

Kurushin, N.I., Evolution of Etiologic-Trophic Groups of Bivalve Mollusks and Environments in the Olenekian (Triassic) Basin of Siberia, *Sreda i Zhizn' v Geologicheskom Proshlom. Aspekty Evolyutsii Organizmov i Sredy* (Habitat and

Life in Geological Past. Aspects of Evolution of Organisms and Environments), Novosibirsk: Nauka, 1990, pp. 91 - 100.

Lipatova, V.V., Pikalova, O.V., Basilova, O.K., Zhidovinov, S.N., *et al.*, The Ultrathick Section of the Masteksai Horizon (Middle Triassic) in the Southern Part of the Ural–Volga Interfluve Area, *Geologiya Nefti i Gaza*, 1992, no. 9, pp. 19 - 22.

Lipatova, V.V., Volozh, Yu.A., and Samodurov, V.I., *Trias Prikaspiiskoi Vpadiny i Perspektivy Ego Neftegazonosnosti* (The Triassic of the Caspian Sea Depression and Its Oil Resources), Moscow: Nedra, 1982.

Lipatova, V.V., Zhidovinov, S.N., Iskuzhiev, B.A., Kiselevskii, F.Yu., *et al.*, *Stratigrafiya Srednetriasovykh Otlozhenii Mezhdurech'ya R. Uil i Emba* (Stratigraphy of the Middle Triassic Deposits of the Uil–Emba Interfluve Area), Available from VIEMC, Moscow, 1991, no. 1014-MG.

Movshovich, E.V., Triassic System, *Geologiya SSSR*, Moscow: Nedra, vol. 46, 1970, pp. 228 - 255.

Nazarevich, B.P., and Nazarevich, I.A., Mesozoic Formations of Eastern and Central Ciscaucasia as Indicators of Sedimentation Evolution and Development of the Scythian Plate, *Obstanovki Osadkonakopleniya i Ikh Evolyutsiya* (Depositional Environments and Their Evolution), Moscow: Nedra, 1984, pp. 150 - 162.

Reshenie 2-go Mezhvedomstvennogo Regional'nogo Stratigraficheskogo Soveshchaniya po Mezozoyu Kavkaza (Trias) (The Resolution of the 2nd Interdepartmental Regional Stratigraphic Meeting on the Mesozoic of the Caucasus: Triassic), Leningrad: Vsesoyuzn. Geol. Inst. (VSEGEI), 1979.

Savelieva, L.M., *Trias Vostochnogo Predkavkaz'ya* (The Triassic of Eastern Ciscaucasia), Moscow: Nedra, 1978.

Verzilin, N.N., *Metody Paleogeograficheskikh Issledovanii* (Methods of Paleogeographic Investigations), Leningrad: Nedra, 1979.

Yapaskurt, O.V., On Evolution of Sedimentogenesis and Lithogenesis along Platform Margins at the Paleozoic–Mesozoic Boundary. Presentation 2. Comparative Analysis of Depositional Environments in the Permian–Triassic Basins of Western Areas of Verkhnyaya Yara Region, Eastern Ciscaucasia, and Peculiarity of Lithogenesis during the Triassic, *Litologiya i Poleznye Iskopaemye*, 1991, no. 2, pp. 90 - 103.

Zhidovinov, S.N., Stratigraphic Correlation of Triassic Deposits of Mangyshlak, Ustyurt, Caspian Depression, and Eastern Ciscaucasia, *Byull. MOIP. Otd. Geol.*, 1993, vol. 68, no. 5, pp. 72 - 78.

Zhidovinov, S.N., Stratigraphy of Triassic Deposits of Mangyshlak and Ustyurt, *Cand. Sci. (Geol.) Dissertation*, Leningrad: Vsesoyuzn. Geol. Inst. (VSEGEI), 1985.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 264 - 271. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 67 - 74.
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Changes in Brachiopod Assemblages during the Aptian and Albian

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Abstract – A study of Aptian–Albian brachiopod assemblages revealed that their composition changed variably during the indicated interval. Most significant changes were at the Late Aptian–Early Albian and Late Albian–Cenomanian boundaries. At both times species and genera characteristic of the Early Cretaceous decreased in their number, being replaced by new genera, many of which existed during the Late Cretaceous. At the above boundaries there was also a substantial rennovation of the species composition.

CHANGES IN GENERIC COMPOSITION

The Aptian brachiopods were distributed mainly throughout the Mediterranean, and to a lesser extent, in the Boreal seas (Middlemiss, 1972; Middlemiss and Rowson, 1971; Lobacheva, 1978; Smirnova, 1984, 1990; Figs. 1 - 3).

Similar brachiopod assemblages of the Aptian and Albian are known from Europe and Mexico. At that time, the American continents and Eurasia were closer than now, because the sea-floor spreading between both continental areas began in the Jurassic. It is likely that the Mediterranean and North American basins communicated during certain intervals of the Early Cretaceous. For example, R.W. Imlay (1940) pointed to the similar composition of ammonite, gastropod, and bivalve assemblages from those basins. B.T. Yanin (1989) reported on comparable groups of their Early Cretaceous rudists, and T.N. Smirnova (1984) correlated the Hauterivian and Albian brachiopods from the regions under consideration. This may suggest that larvae survived transportation over a smaller distance as compared to the present space between North America and Europe. Originating at the opening stage of the North Atlantic, the ancient Gulf Stream could have been substantially conducive to such a transportation. This may be just an explanation for the typical Mediterranean brachiopods, corals, and tropical plants that appeared in eastern Greenland during the Aptian (Saks and Nal'nyaeva, 1966; Arkell, 1956; Stevens, 1973; Ager, 1971, 1974, 1975).

The most numerous brachiopod genera were observed in the Early Aptian deposits (Fig. 4). *Sulcirhynchia, Sardope, Loriolithyris, Kachathyris, Belothyris, Vaniella, Tulipina*, and *Oblongarcula* ceased to exist at this time. In the Middle Aptian, there were 21 genera, and only one of them, the *Cruralina* genus, disappeared during that time. The most significant extinction was in the Late Aptian, when 10 of 23 genera terminated their evolution (*Prochlidonophora, Moutonithyris, Cyrtothyris, Tropeothyris, Rhombothyris, Peculneithyris, Eudesia, Arenaciarcula, Vectella*, and *Bifolium*). Three of the extinct genera are known since the Jurassic. These are *Monticlarella* of the Oxfordian, *Tropeothyris* of the Tithonian, and *Eudesia* of the Bathonian. Other genera originated at various stages of the Early Cretaceous. *Moutonithyris, Loriolithyris, Belothyris*, and *Sulcirhynchia* are known since the Berriasian, *Cruralina* originated in the Valanginian, *Cyrtothyris, Bifolium*, and *Oblongarcula* appeared in the Hauterivian, while *Kachathyris*, and probably *Prochlidonophora* are of the Barremian genera. *Sardope, Rhombothyris, Vaniella, Tulipina, Oblongarcula, Arenaciarcula*, and *Vectella* are restricted in occurrence only by the Aptian.

Genera, originated in the Aptian, compose nearly half of the extinct forms. Those known to exist in the Early Aptian are the *Sardope, Vaniella, Oblongarcula*, and *Gemmarcula* genera. The *Platythyris* genus is from the Middle Aptian time, and *Rhombothyris, Arenaciarcula*, and *Vectella* are of Late Aptian origin. Still, the Aptian, especially its late interval, was a period when the number of brachiopod genera notably decreased, because 19 of 33 known genera of this time terminated their evolution, being replaced only by 9 new genera. So, we may conclude that the Late Jurassic–Early Cretaceous stage in the brachiopod evolution terminated at the end of the Aptian. However, many genera survived the entire Early Cretaceous, and existed during the Aptian. Among them, the Jurassic genera are scarce, being represented by *Cyclothyris* and *Symphythyris*, known since the Tithonian, and by *Nucleata*, the earliest forms of which were recognized in the Kimmeridgian deposits. The Early Cretaceous genera *Sellithyris* and *Psilothyris* appeared in the Berriasian, *Praelongithyris*, in the Valanginian, *Clathrithyris, Oblongarcula*, and Boubeithyris, in the Hauterivian, *Burrirhynchia, Orbirhynchia*, and *Pseudoaulacothyris*, in the Barremian. The extinction time for most Aptian genera is the Albian. Two of them, *Oblongarcula* and

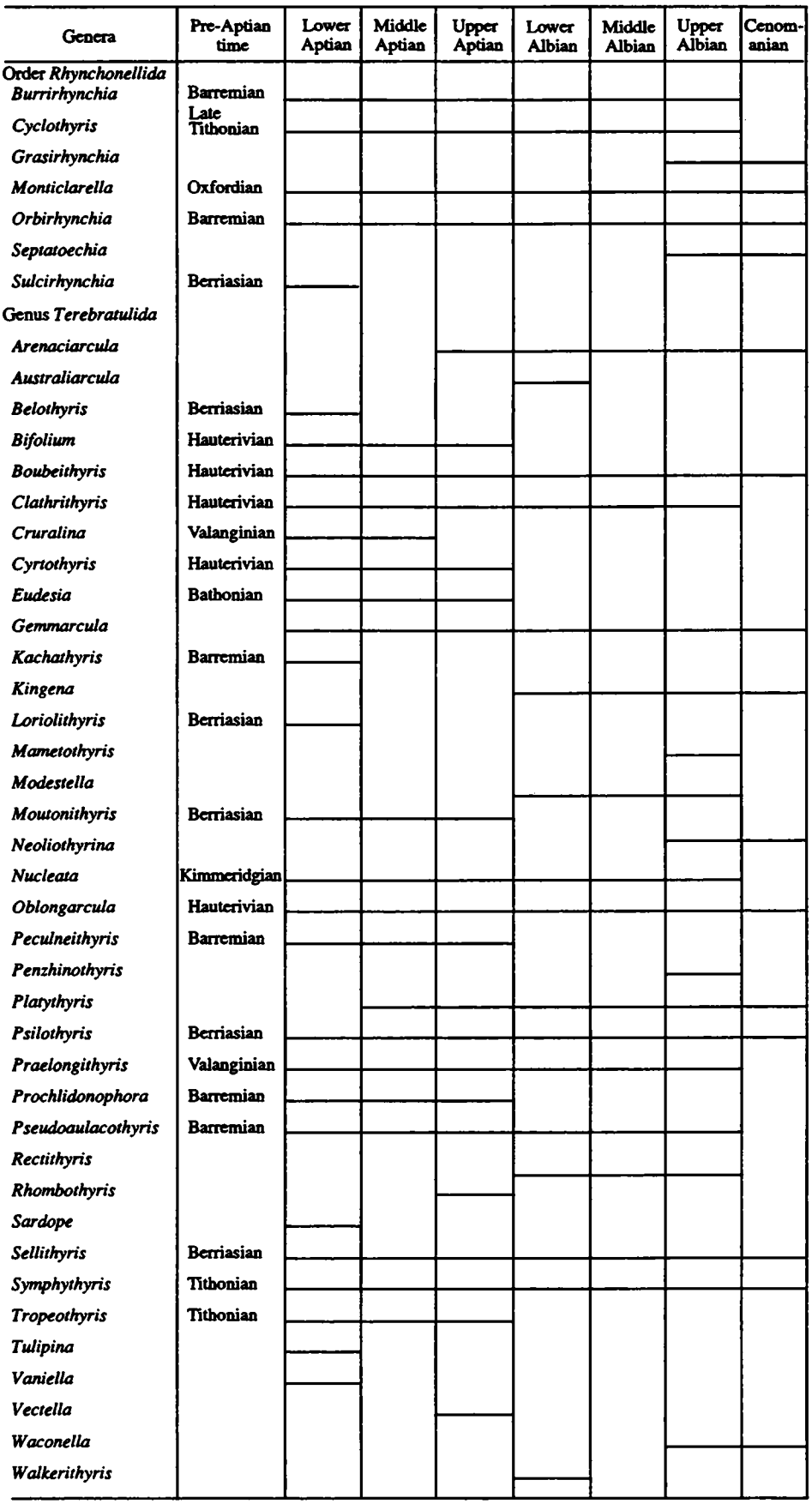


Fig. 1. Stratigraphic distribution of brachiopod genera in the Aptian and Albian deposits.

Boubeithyris, disappeared in the Cenomanian. *Cyclothyris* died out in the Turonian, and *Orbirhynchia* disappeared in the Santonian.

The Albian is characterized by 26 brachiopod genera. Eleven new genera of this period replaced the same amount of extinct groups, but this proportion was not uniform throughout the Albian. Among the 19 genera of the Early Albian, six appeared for the first time. They include *Rectithyris, Boubeithyris, Kingena, Modestella, Walkerithyris*, and *Australiarcula*. The last two genera disappeared at the end of the Early Albian. The Middle Albian was a period containing a minimal

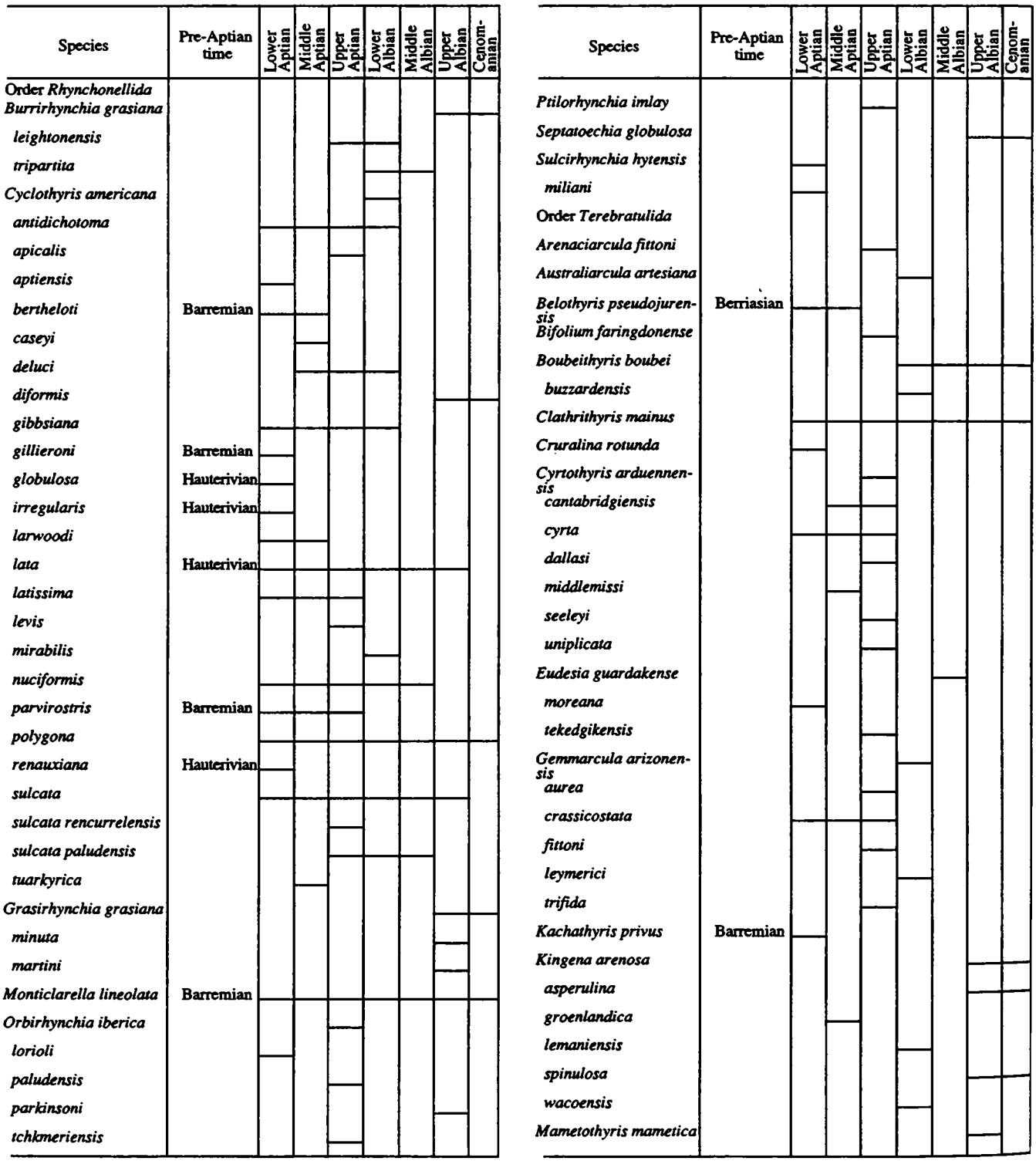
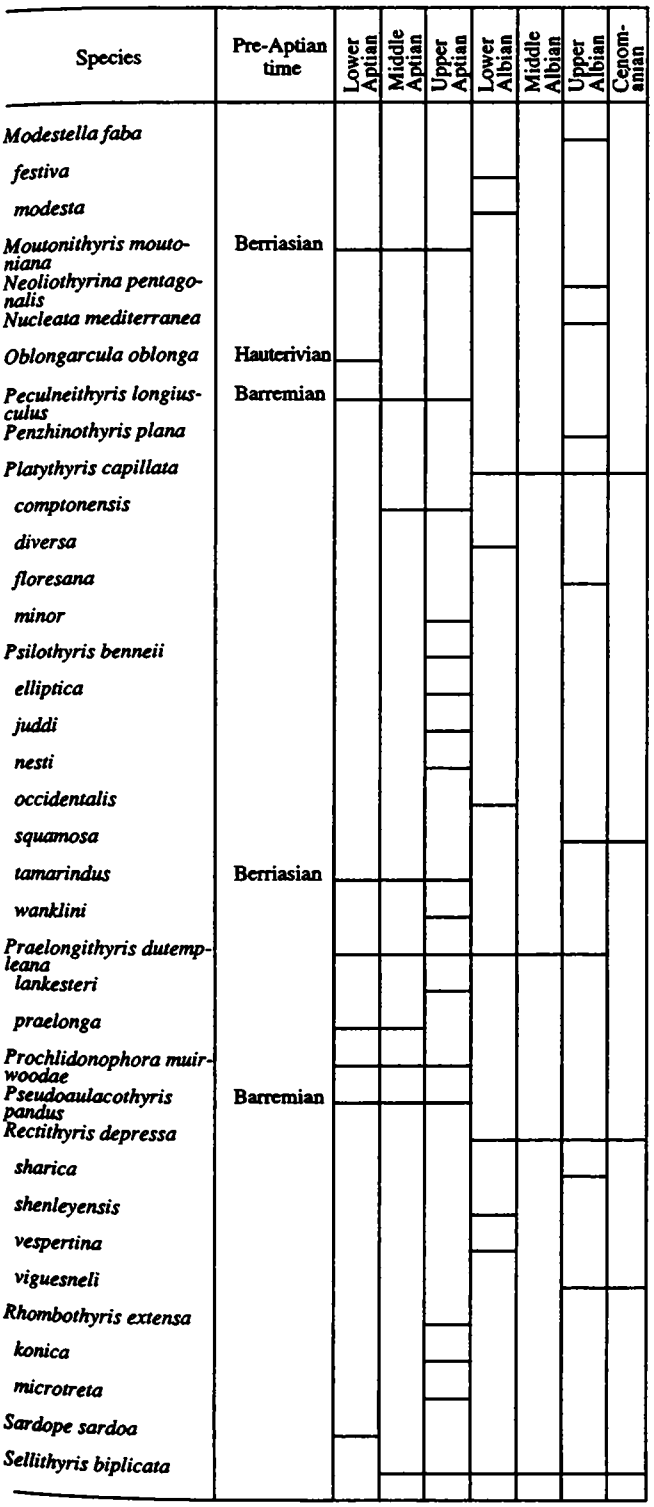
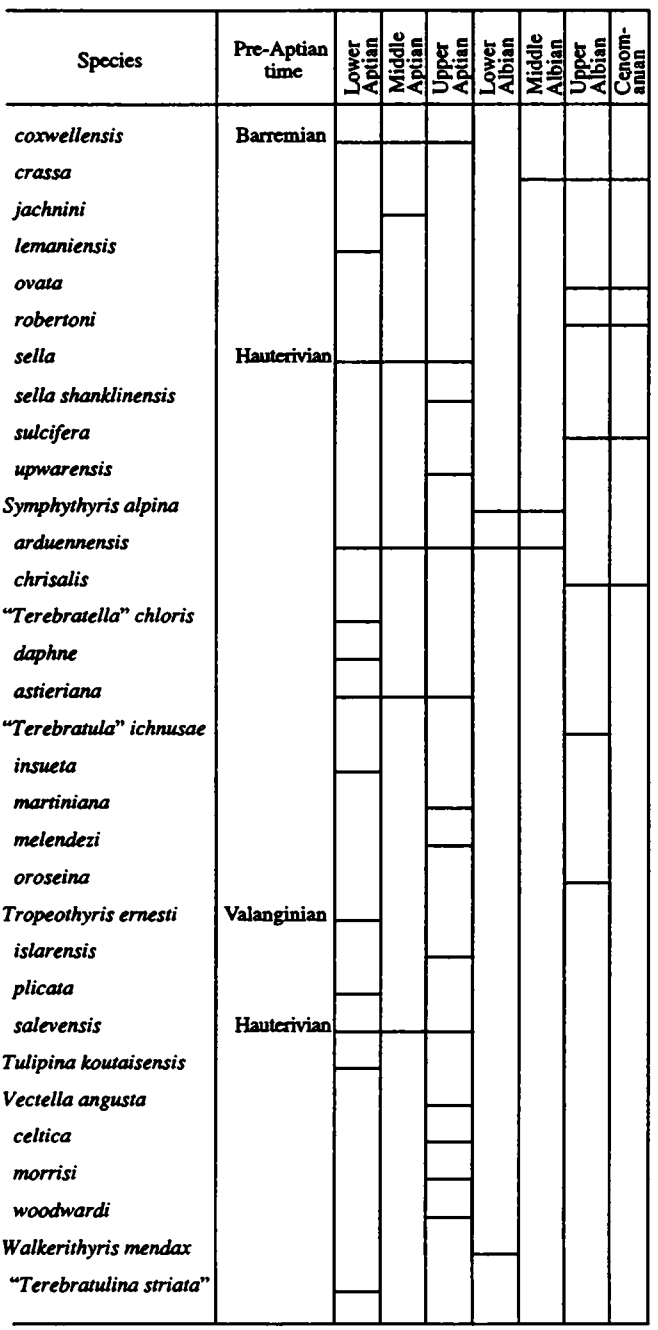


Fig. 2. Stratigraphic distribution of brachiopod species in the Aptian and Albian deposits.

number of the brachiopod genera (17), undergoing no changes in their specific composition. The relation between new and extinct genera of the Late Albian was different as compared to its earliest time. At this period, there were 22 genera, five of which were new: *Grasirhynchia, Septatoechia, Penzhinothyris, Mametothyris,* and *Waconella*. The number, which is nearly two times larger (9), of the extinct genera includes *Burrirhynchia, Nucleata, Praelongithyris, Penzhinothyris, Mametothyris, Pseudoaulacothyris, Gemmarcula, Modestella,* and *Clathrithyris*.

The Albian brachiopods had a much wider geographic distribution as compared to the Aptian assem-





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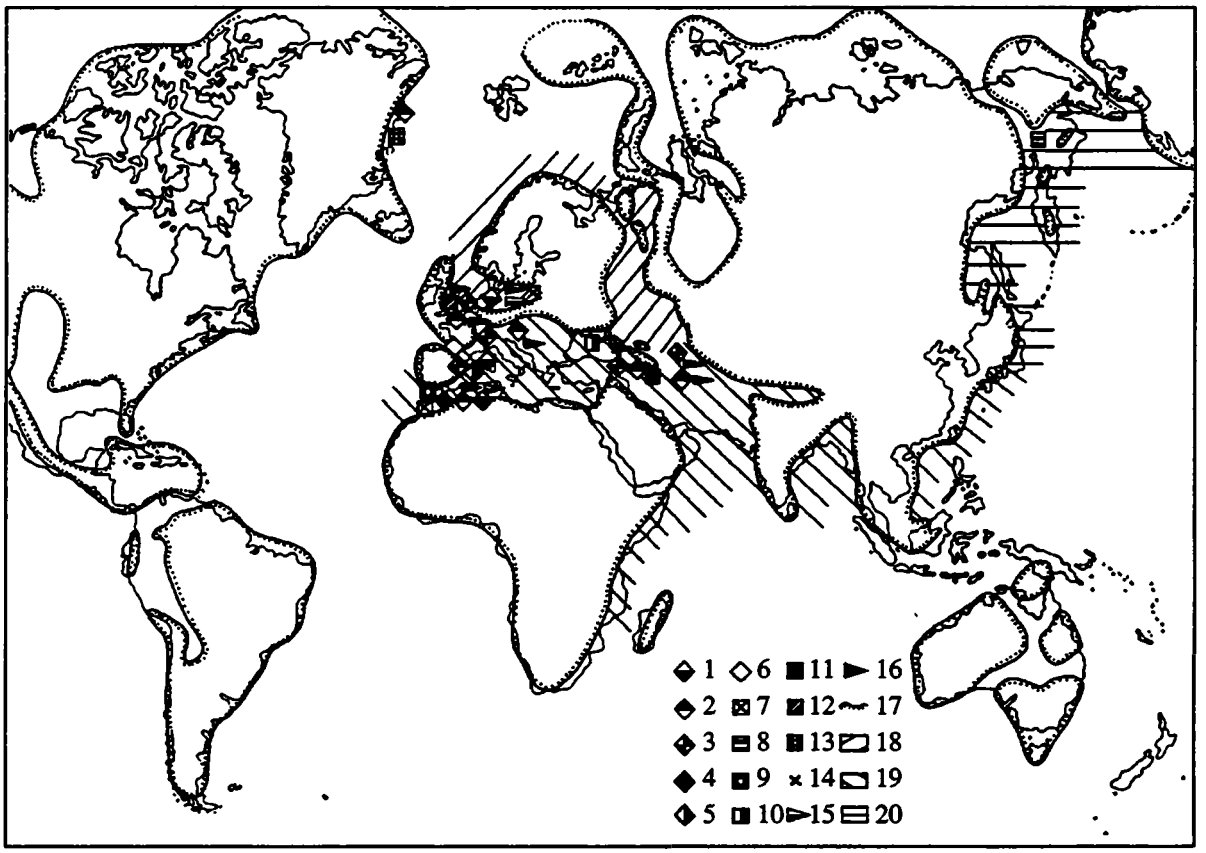

Fig. 3. Paleozoogeographic scheme of the Aptian seas according to brachiopods (Smirnova, 1984).

1 – *Platythyris*; 2 – *Sellithyris*; 3 – *Praelongithyris*; 4 – *Cruralina*; 5 – *Tropeothyris*; 6 – *Cyrtothyris*; 7 – *Belothyris*; 8 – *Clathrithyris*; 9 – *Orbirhynchia*; 10 – *Kachathyris*; 11 – *Gemmarcula*; 12 – *Eudesia*; 13 – *Nucleata*; 14 – *Burrirhynchia*; 15 – *Monticlarella*; 16 – *Cyclothyris*; 17 – land boundary; 18 – boreal province; 19 – Mediterranean province; 20 – Pacific province.

blages. They occur all over the Earth's continents except for South America (Fig. 5).

Genera characteristic of the Albian only are *Australiarcula, Walkerithyris*, and *Modestella*, occurring in the western Mediterranean, and two genera from Kamchatka: *Penzhinothyris* and *Mametothyris*. The former group appeared in the Early Albian, and specimens of the latter are known since the late period of this stage. Eleven Albian genera do not occur in the post-Albian time. The Albian is the last stage in evolution of the *Nucleata* genus, which appeared in the Kimmeridgian and existed throughout the Early Cretaceous. Other genera originated at various stages of the Early Cretaceous: *Sellithyris* and *Psilothyris* in the Berriasian, *Praelongithyris* in the Valanginian, *Clathrithyris* in the Hauterivian, *Pseudoaulacothyris* and *Burrirhynchia* in the Barremian, and *Sardope* in the Early Aptian. The extinction of typical Early Cretaceous species and forms of the Late Jurassic origin is peculiar to the Albian time. The rest of the Early Cretaceous genera disappeared in the Cenomanian. These are *Oblongarcula* and *Boubeithyris* of the Hauterivian time, and *Platythyris, Arenaciarcula*, and *Gemmarcula* recorded since the Aptian. Such long-lived genera as *Cyclothyris* (Late Tithonian–Turonian) and *Orbirhynchia* (Barremian–Santonian) are probably collective. The Albian genera *Neoliothyrina, Grasirhynchia, Rectithyris*, and *Waconella* also became extinct in the Cenomanian.

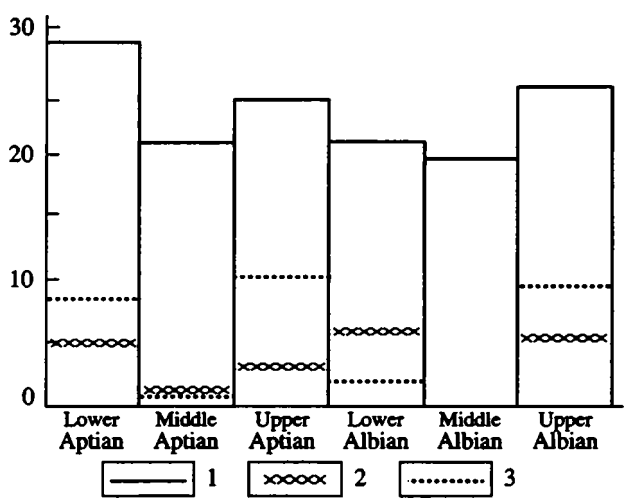

Fig. 4. Quantitative relations between brachiopod genera from the Aptian and Albian deposits.

1 – Total number of genera; 2 – number of new genera; 3 – number of extinct genera.

Therefore, the Late Aptian and Late Albian are periods of the most significant changes in generic compo-

sitions, while the maximum origination of new generic groups correspond to the Early Aptian and Early Albian.

CHANGES IN SPECIFIC COMPOSITION

The study on species assemblages of the Early, Middle, and Late Aptian times revealed fluctuations in brachiopod diversity and different relations between appearing and disappearing taxa (Figs. 5, 6). The most notable changes in species composition were in the Late Aptian. As compared to its early and middle intervals, it was a time of maximum species diversity, whose number was 57. Their lesser part includes species inherited from the Early and Middle Aptian, and 36 forms originate in the Late interval of the stage. Like most of the Early-Middle Aptian species, all new forms died out at the end of the Aptian. The total number of extinct species is 54. Only five of the Late Albian forms transited into the Early Albian: *Cyclothyris gibbsiana, C. antidichotoma, C. sulcata, Burrirhynchia leightonensis*, and *Praelongithyris dutempleana.*

The Early Aptian brachiopods include 47 species, 29 of which appeared at this time, and 20 became extinct: *Cyclothyris aptiensis, C. gillieroni, C. globulosa, C. irregularis, C. renauxiana, Orbirhynchia lorioli, Sulcirhynchia hytensis, S. miliani, Cruralina rotunda, Eudesia moreana, Kachathyris privus, Oblongarcula oblonga, Sardope sardoa, Sellithyris lemaniensis, "Terebratella" chloris, "T." daphne, "Terebratula" insueta, Tropeothyris ernesti, T. plicata*, and *Tulipina koutaisensis*. Total number of brachiopod species increased slightly.

Among 36 species of the Middle Aptian, nine appeared in this period: *Cyclothyris caseyi, C. deluci, C. tuarkyrica, Cyrtothyris cantabrigiensis, Sellithyris jachnini, S. biplicata, Platythyris comptonensis, "Terebratula" striata*, and *Kingena groenlandica.* Nine extinct species of the Middle Aptian include *Cyclothyris bertheloti, C. larwoodi, C. caseyi, C. tuarkyrica,*

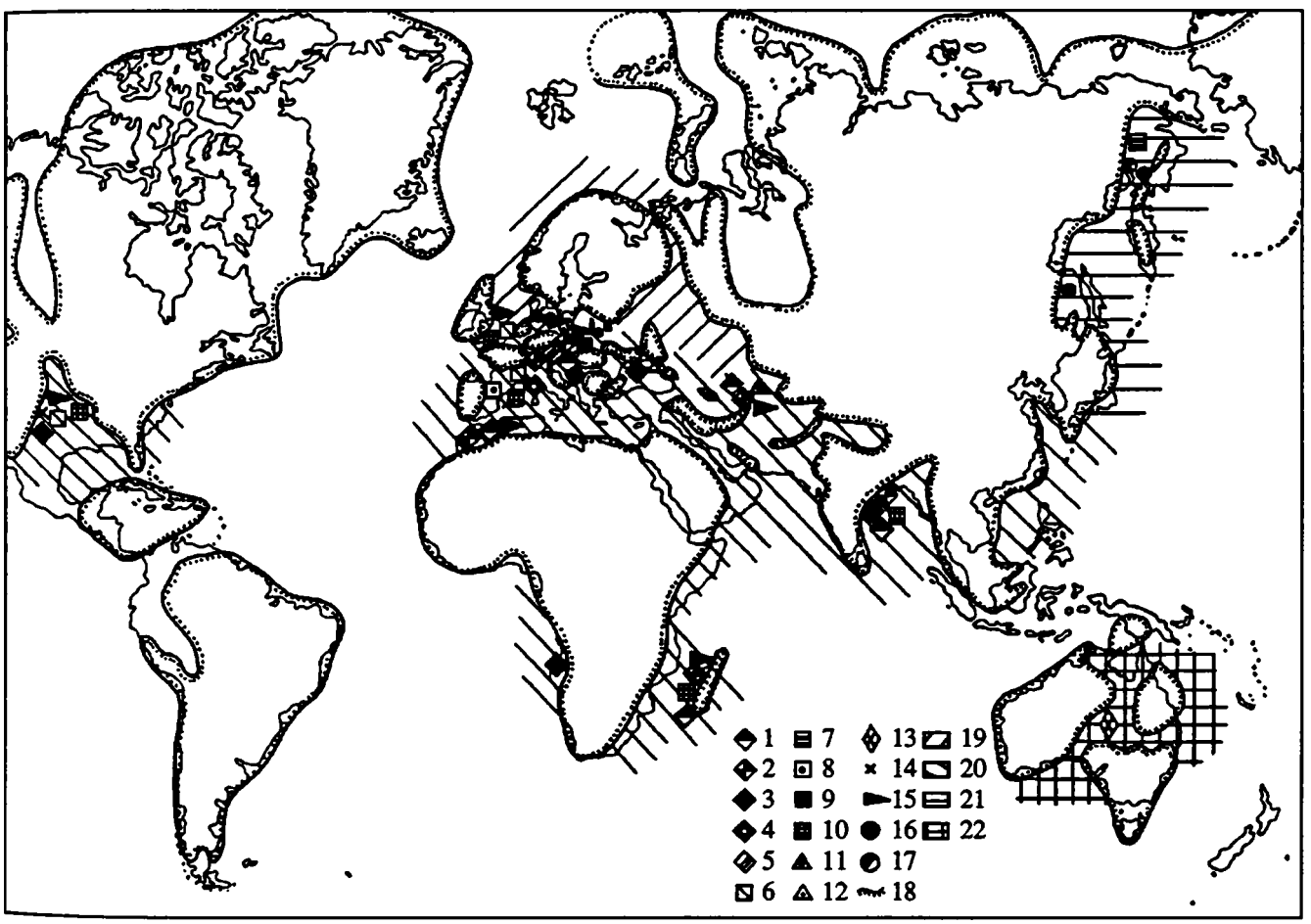

Fig. 5. Paleozoogeographic scheme of the Albian seas according to brachiopods (Smirnova, 1984).

1 – *Sellithyris*; 2 – *Praelongithyris*; 3 – *Boubeithyris*; 4 – *Nucleata*; 5 – *Platythyris*; 6 – *Psilothyris*; 7 – *Clathrithyris*; 8 – *Gemmarcula*; 9 – *Arenaciarcula*; 10 – *Kingena*; 11 – *Orbirhynchia*; 12 – *Burrirhynchia*; 13 – *Australiarcula*; 14 – *Monticlarella*; 15 – *Cyclothyris*; 16 – *Penzhinothyris*; 17 – Mametothyris; 18 – land boundary; 19 – European province; 20 – Mediterranean province; 21 – Pacific province; 22 – Australian province.

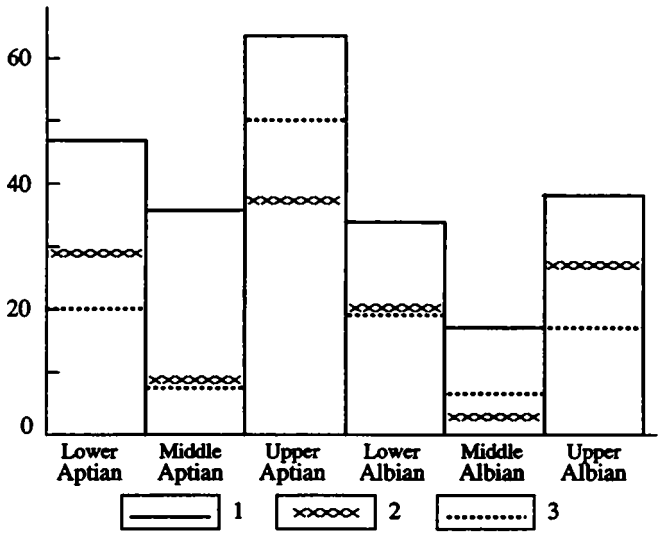

Fig. 6. Quantitative relations between brachiopod species from the Aptian and Albian deposits.

1 – Total number of species; 2 – number of new species; 3 – number of extinct species.

Belothyris pseudojurensis, Sellithyris jachnini, Cyrtothyris middlemissi, Kingena groenlandica, and *Praelongithyris praelonga.* In all, the brachiopod species of the Middle Aptian retained the initial diversity.

As compared to the Late Aptian, the Early Albian brachiopod assemblage is essentially different in generic and specific compositions. As was noted, the Early Albian lacked the characteristic Aptian genera: *Cruralina, Moutonithyris, Cyrtothyris, Tropeothyris, Loriolithyris, Sulcirhynchia, Rhombothyris, Russiella, Vectella,* and others. In total, 17 genera of the Early Cretaceous did not transit into the Albian, and 50 of 64 registered species of the Late Aptian died out at the Aptian–Albian boundary. The extinct species include *Cyclothyris apicalis, C. latissima, C. levis, C. parvirostris,* and others presented in Fig. 2. So, the time of the most radical changes in the evolution of the Aptian–Albian brachiopods is marked exactly by this boundary.

There are known 34 brachiopod species of the Early Albian, seven of which appeared during the Early-Middle Aptian period: *Symphythyris arduennensis, Cyclothyris deluci, C. antidichotoma, C. gibbsiana, C. sulcata, Burrirhynchia leightonensis,* and *Praelongithyris dutempleana.* Twenty species came into being during the Early Albian, and 19 forms became extinct by the Middle Albian: *Burrirhynchia leightonensis, Cyclothyris americana, C. antidichotoma, C. deluci, C. gibbsiana, C. mirabilis, Australiarcula artesiana, Boubeithyris buzzardensis, Gemmarcula arizonensis, G. leymerici, Kingena lemaniensis, K. wacoensis, Modestella festiva, M. modesta, Platythyris diversa, Psilothyris occidentalis, Rectithyris shenleyensis, R. vespertina,* and *Walkerithyris mendax.* Only *Burrirhynchia tripartita* and *Symphythyris alpina* continued to exist later.

The Middle Albian assemblage consists of 17 species including forms of the Early Albian (*Burrirhynchia tripartita, Rectithyris depressa, Symphythyris alpina*), and the Aptian (*Cyclothyris sulcata, C. sulcata paludensis, C. nuciformis, Praelongithyris dutempleana,* and *Symphythyris arduennensis*). Two species, *Sellithyris crassa* and *Eudesia guardakense,* are of Middle Albian origin, and six forms disappeared in this time: *Cyclothyris sulcata paludensis, C. nuciformis, Burrirhynchia tripartita, Symphythyris alpina, S. arduennensis,* and *Eudesia guardakense.*

The Late Albian brachiopods were more diverse. They include 38 species, seven of which were inherited from the Aptian: *Cyclothyris lata, C. polygona, C. sulcata, Monticlarella lineolata, Sellithyris biplicata, Praelongithyris dutempleana,* and *Clathrithyris mainus.* Brachiopods of the Late Albian origin encompass 27 species, and 15 forms died out in this period: *Cyclothyris lata, C. sulcata, Orbirhynchia parkinsoni, Grasirhynchia minuta, G. martini, Praelongithyris dutempleana, "Terebratula" ichnusae, "T." oroseina, Platythyris floresana, Rectithyris sharica, Neoliothyrina pentagonalis, Nucleata mediterranea, Mametothyris mametica, Penzhinothyris plana,* and *Modestella faba.*

Therefore, the most substantial changes in species composition occurred in the Late Aptian time, when 50 of 64 known forms, i.e., the largest part of the brachiopod assemblage, ceased to exist. A significant modification of species composition also occurred in the Early Albian, when 19 of 34 species became extinct. The maxima of speciation are confined to the Early and Late Aptian (29 and 37 new species respectively). The similar rate of evolutionary changes was characteristic of the Early Albian when 20 new species appeared. Thus, comparing the generic and specific assemblages, we can see that extreme changes in taxonomic composition occurred in the Late Aptian and Late Albian. They were of less importance during the Early Aptian and Early Albian, and the Middle Aptian and Middle Albian are periods of insignificant variations in the diversity of the brachiopod taxa.

Reviewers G. T. Ushatinskaya and Yu.B. Gladenkov.

REFERENCES

Ager, D.V., Brachiopods at the Jurassic–Cretaceous Boundary, *Mém. Bur. Rech. Géol. et Miniéres,* 1975, no. 86, pp. 150 - 162.

Ager, D.V., Space and Time in Brachiopod History, Faunal Provinces in Space and Time, *Geol. Journ. Spec. Issue,* 1971, no. 4, pp. 95 - 110.

Ager, D.V., The Western High Atlas of Morocco in the History of the North Atlantic, *Proc. Geol. Assoc.,* 1974, vol. 85, part 1, pp. 23 - 41.

Arkell, W.J., *Jurassic Geology of the World,* Edinburgh–London, 1956, vol. 14.

Imlay, R.W., Neocomian Fauna of Northern Mexico, *J. Paleont.* (Washington), 1940, pp. 138 - 142.

Lobacheva, S.V., Stratigraphic Significance of the Early Cretaceous Brachiopods from Middle Asia, *Ezhegodnik VPO*, 1978, vol. 21, pp. 228 - 241.

Middlemiss, F.A., The Geographical Distribution of Lower Cretaceous Terebratulacea in Western Europe, *Boreal Lower Cretaceous*, Amsterdam: Hallama, 1973, pp. 111 - 120.

Middlemiss, F.A. and Rowson, P.E., Faunal Provinces in Space and Time: Some General Considerations, Faunal Provinces in Space and Time, *Geol. Journ. Spec. Issue*, 1971, no. 4, pp. 199 - 210.

Saks, V.N., and Nal'nyaeva, T.I., *Verkhneyurskie i Rannemelovye Belemnity na Severe SSSR. Roda Pachyteuthis i Acroteuthis* (Late Jurassic and Early Cretaceous Belemnites of the Southern USSR. Genera *Pachytuethis* and *Acroteuthis*), Moscow–Leningrad: Nauka, 1966.

Smirnova, T.N., *Rannemelovye Brakhiopody (Mopfologiya, Sistematika, Filogeniya, Znachenie dlya Biostratigrafii i Paleozoografii)* (Early Cretaceous Brachiopods: Morphology, Taxonomy, Phylogeny, Biostratigraphic, and Paleozoographic Significance), Moscow: Nauka, 1984.

Smirnova, T.N., *Sistema Rannemelovykh Brachiopod* (System of the Early Cretaceous Brachiopods), Moscow: Nauka, 1990.

Stevens, G.R., Cretaceous Belemnites, *Atlas Paleobiogeography*, Amsterdam: Hallama, 1973, pp. 384 - 399.

Yanin, B.T., *Yurskie i Melovye Rudisty* (Jurassic and Cretaceous Rudists), Moscow: Nauka, 1989.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 272 - 283. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 75 - 86.
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The Suvlukaya Paleogene Section (the Crimea)

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Abstract – The Suvlukaya section (the southwestern Crimean Mountains) is suggested as one of the Paleogene reference sections of the European Paleobiogeographical Province (EPP). The Thanetian, Ypresian and Lutetian stages were distinguished in this locality according to macro- and micropaleontological data and calcareous nannofossils.

More than 80 years ago Lange and Mirchink (1909) proposed that, according to molluskan fauna, deposits near the town of Bakhchisarai could be correlated with the Paleogene sections of Western Europe. By the beginning of the 1950s deposits of the Thanetian, Ypresian, and Lutetian stages were recognized in the southwestern part of the Crimean Mountains (Bykov, 1971; Zubkovich, 1956).

Attempts of more detailed correlation of the Paleogene deposits of the Crimea with those of Western Europe came across significant difficulties. The main difficulty is the absence of a clear and uniform conception among European scientists concerning the interrelations of various regional stratigraphical subdivisions. This results mainly from the fact that facially complicated Paleogene beds in Europe (including stratotypes of geological stages) are poorly exposed. Outcrops with distinct stratigraphic boundaries are rare. At the same time, Paleogene deposits are well exposed in the southwestern Crimea. There are several sections with a vertical succession of well represented units convenient for lithologic and paleontologic studies (Muratov, 1960; Menner, 1983). Abundant and well preserved microfossils distinguish Crimean sections from that of the Lower Volga region, northern Caucasus, and other parts of the European paleobiogeographical province (Menner, 1983).

That is why, in the early 1960s, the stratigraphic scheme of the Russian Paleogene deposits was suggested to be based on the Crimean sections (Muratov and Nemkov, 1959, 1960; *Resolutions* ..., 1963) for the purposes of geological surveys and the elaboration of legends for geological maps.

However, some scientists (Leonov, 1963; Leonov *et al.*, 1965) objected to this idea, stating that it is premature to consider the above local subdivisions as stages of a general scale. It was noted that the existing regional Paleogene scheme suffers from grave shortcomings, and "is in need of further improvement, though we should not reject it, replacing it with a new scale, the advantages of which are rather questionable and unclear. Such a substitution seems to be speculative, because it will probably add new difficulties to the present understanding and elaboration of the regional stratigraphy of Paleogene deposits of the USSR" (Leonov, 1963). However, the Paleogene commission of the Interdepartmental Stratigraphic Committee (ISC) did not take this into account and adopted this premature scheme based on the Paleogene "reference section" of the Bakhchisarai region (*Resolutions* ..., 1963). Several works concerning the "Bakhchisarai Paleogene stratotype section" appeared, but stratigraphic studies proved Leonov's cautions. It was revealed that subdivisions of the "Bakhchisarai Paleogene stratotype section of the Crimea" did not correspond to the stages of the international stratigraphic scale, and can be considered only as subdivisions of regional scale, i.e., the regional stages (*Resolutions* ..., 1983).

The key sequence of the rather incorrectly named "Bakhchisarai stratotype section" is that of the Suvlukaya locality.

LITHOLOGIC CHARACTERISTICS

The ancient part of the town of Bakhchisarai is situated in the deep valley of the Churyuksu River. The right valley slope in the eastern suburb of the town is steep with scarps and peculiar weathering forms (Fig. 1). Tatars call this part of the slope Suvlukaya. The Paleogene section exposed here is one of the most complete in Europe. It has been well known for a long time, and is graphically illustrated in several works (Vasilenko, 1952; Zhizhchenko, 1965; Muratov and Nemkov, 1960; Nemkov and Barkhatova, 1961; *Putevoditel'* ..., 1971).

(1) The Suvlukaya beds overlie the Danian and Montian deposits of the Salachik (Starosel'e) section situated 1 km to the east of it (*Putevoditel'* ..., 1971).

The following layers overlie the uneven and eroded surface of the Montian limestones (layer 2 in Fig. 2):

(2) Light grey and greenish grey slightly sandy marls, with glauconite at the bottom (1.6 m).

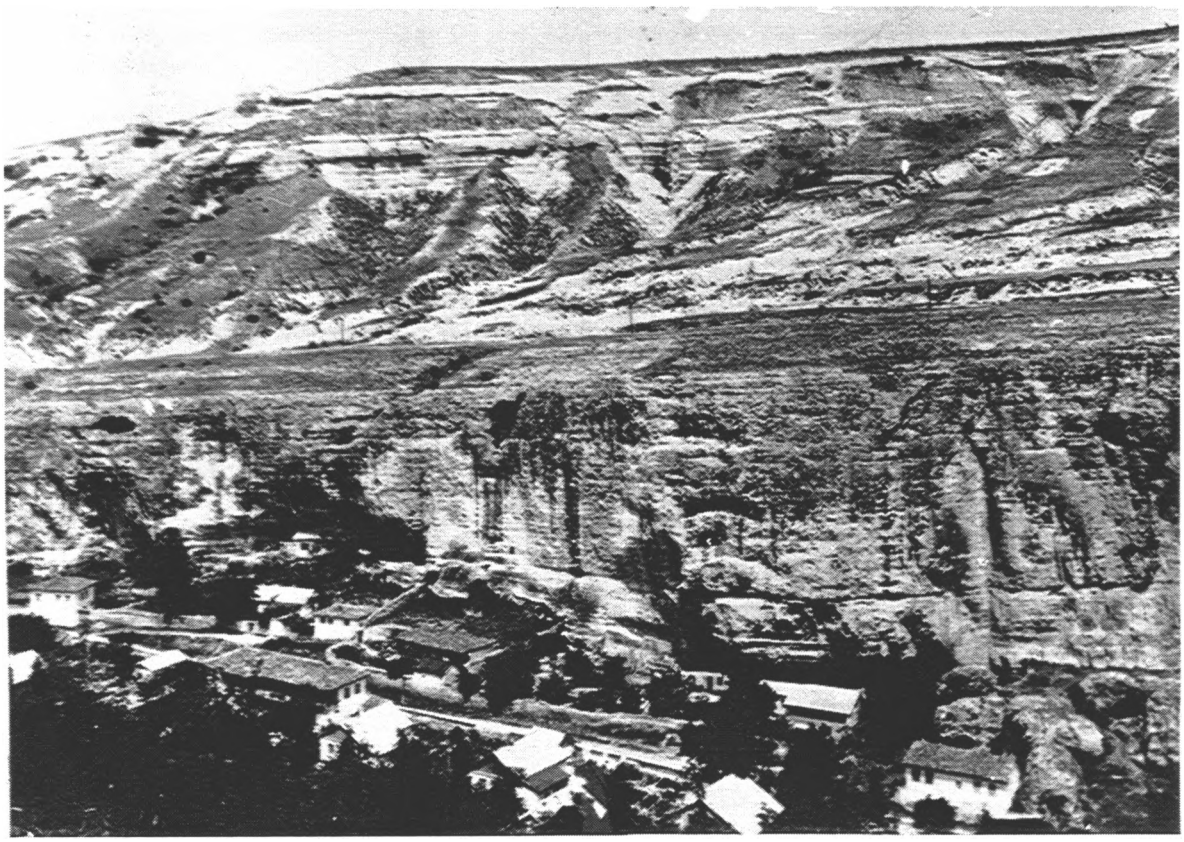

Fig. 1. Mt. Suvlukaya. Photo by M.Yu. Nikitin.
Below the scarp composed of the Danian–Montian limestones. A structural terrace formed over the top of the limestones is the base of the section (beds 2 - 7).

(3) Light grey marls, which become nearly white when dried, with silicified grey and dark grey parts substituting sponges ("sponge horizon" of Zubkovich, 1956) (1.8 m).

(4) Light grey marls, gaining a yellowish grey color after weathering, more dense at the top, than at the bottom (10.2 m). The bed's top is uneven with thalassinoid pores filled with the overlying materials.

(5) Brownish grey and dark grey calcareous clays with a greenish tint. At the bottom of the bed dark green sandy clays are enriched in glauconite and contain scattered phosphorite concretions (0.2 m). Carbonate content in clays increases upwards (17 - 18 m).

(6) Clays similar to those of bed 5 form the base of the bed. They include marl interlayers (0.1 - 0.25 m) with abundant bivalve shells and tests of large foraminifers. Upwards the amount of interlayers and abundance of foraminifera tests grow, thus allowing us to term this rock "nummulitic marl."

Some marl layers are impermeable and cause humidification of the slope in spring and after heavy rains. That is why this part of the slope is called Suvlukaya – "water cliff."

(7) White, slightly yellowish massive limestones composed of large foraminifera remnants – "nummulitic limestones."

Lithologically these layers form three members: marls (beds 2 - 4), clays with marl interlayers at the top of the member (beds 5 and 6), and nummulitic limestones (in the described section their lower part is represented by the Bed 7).

The three-membered Paleogene sections also occur in the other regions of the Crimea mountains. These sections have two characteristic features. First, their thickness increases to the southwest from Bakhchisarai (Kacha, Bel'bek, Chernaya) and decreases in the northeastern direction (Bodrak), completely thinning out at the Simferopol' uplift. Second, they include two unconformities. The marls (beds 2 - 4) truncate the Danian–Montian limestones with a slight angular unconformity. The clays (beds 5 and 6) unconformably (dip angle 3° - 4°) overlie different deposits: from marls (beds 2 - 4) and the Danian–Montian limestones in southwestern Crimea to various Cretaceous horizons in the Simferopol' uplift.

Table 1. Macrofossils of the Suvlukaya section

Number in Fig. 2	Forms	Number in Fig. 2	Forms
	Pelecypods	9	*Plicatula* cf. *cyclostroides* Traub
10	*Cardita nova* Zubkovitsch	22	*Pseudamussium corneum* (Sowerby)
26	*Chlamys opia* Vassilenko	30	*Vulsella caudata* Fraucher
24	*Chl. orcina* Vassilenko		Gastropods
25	*Chl.* ex gr. *parisiensis* (Deshayes)	9	*Ampullina* cf. *chenayensis* Cossmann
17	*Chl. prestwichi* (Morris)	14	*Athleta elevata Sowerby*
23	*Chl. pristina* Vassilenko	11	*Calyptrea* cf. *suessonensis* (d'Orbigny)
29	*Chl. solea* (Deshayes)	4	*Campanile korobkovi* Gorbach
27	*Chl. subimbricata* (Münster)	5	*C. menneri* Gorbach
28	*Chl. veneranda* Vassilenko	12	*Cavoscala bowerbankii* (Mor.)
3	*Corbis montensis* Cossmann	2	*Cerithium semicostatum* Deshayes
4	*C. transversaria* Cossmann	13	*Ficus intermedius* Melleville
11	*Crassatella novella* Zubkovitsch	3	*Pseudoliva robusta* Briart et Cornet
16	*Cucullaea decussata* Parkinson	8	*Turritella* cf. *abichi* Netschaew
14	*Cuc. volgensis* Barbot de Marni	7	*T. bisserialis* Eichwald
8	*Cyprina morrisi* Sowerby	10	*T. kamyschinensis* Netschaew
31	*Deuteromya intustriata* (Archiac)	6	*T.* cf. *leymeriei* Netschaew
20	*Gryphaea antiqua* Schwetzow	1	*T. montensis* Briart et Cornet
32	*G. rarilamella* (Melleville)		Brachiopods
21	*G. pseudovesicularia* (Gümbel)	6	*Gryphus* cf. *bajanianus* (Davidson)
5	*Gryphaeostrea* ex gr. *eversa* (Melleville)	7	*G. kicksii* (Gal.)
2	*Isognomon belbekensis* Gorbach	8	*G. fumanensis* (Memegh.)
18	*Liostrea acutidorsata* (Netschaew)	3	*G. vitreus sullucapensis* Kovaleva
19	*L. reussi* (Netschaew)	9	*Hemithyris chetensis* (Popchadze)
7	*Lucina volgensis* Netschaew	2	*Terebratula mangischlakica* Kovaleva
12	*Miocardia incognita* Zubkovitsch	4	*Terebratulina caputserpentis tauremarginata* Sacco
15	*Nemocardium edwardsi* Deshaes		
6	*Ostrea crimensis* Zubkovitsch	5	*T. striatula* Davidson
13	*Pholadomya koninckii* Nyst	4	*T. woodi* Nyst

MICROPALEONTOLOGIC CHARACTERISTICS

Macrofossils of the section are represented by pelecypods, gastropods, and brachiopods. They are listed in Table 1, and their vertical distribution is shown in Fig. 2. The list of species is based upon our new data and published materials (Vasilenko, 1942; Zubkovich, 1956; Kovaleva, 1961).

It was difficult to correctly use modern generic names recently accepted for a number of forms, which is why we used for them former generic names familiar to geologists: *Corbis* (instead of *Fimbria*), *Cyprina* (*Arctica*), *Gryphaea* (*Pycnodonte*), and some others.

Bed 1 represents the upper part of the Montian limestones.

The remnants of Montian mollusks *Corbis montensis, Ceritium semicostatum*, and *Turritella*, which are probably redeposited from Bed 1, occur at the bottom of Bed 2 (Zubkovich, 1956).

The most characteristic forms of Bed 2 are *Ostrea crimensis, Cyprina morrisi*, and *Lucina volgensis*; shells of *Chlamys prestwichi* also being present.

Pholadomya koninckii and other pelecypods first described by Zubkovich (1956) occur only in the "sponge horizon" (Bed 3). Scarce casts of *Cyprina morrisi* are also present.

Gryphaea antiqua, Chlamys prestwichi, Nemocardium edwardsi, and *Lucina reussi* are most common in Bed 4.

The molluscan assemblage sharply changes in beds 5 and 6 (Fig. 2), where pectinacean become dominant. Oysters are also abundant here, but they are morphologicly different from those of the marl bed. *Cryphaeostrea* ex gr. *eversa, Pseudamusium corneum, Chlamys pristina, C. orcina*, and *C.* ex gr. *parisiensis* were found in Bed 5.

Valves of *C.* ex gr. *parisiensis* still occur in Bed 6 with marl interlayers. Other pectinacean are also com-

mon here, being the most abundant in the marl interlayers. The giant oyster *Gryphaea rarilamella* is characteristic of this bed.

Bed 7 is characterized by a reduced amount of shell remnants (Fig. 2).

So, according to paleontologic characteristics and Zubkovich's conclusion (Zubkovich, 1956), the marl member can be subdivided into three units corresponding to beds 2, 3, and 4, namely into *Cyprina morrisi, Pholadomya koninckii–Cyprina morrisi* ("sponge"), and *Gryphaea antiqua* horizons. The clays of Bed 5 correspond to the *Pseudamussium corneum* Horizon, and those of Bed 6 – to the layers with *Gryphaea rarimella*.

Vertical distribution of the small benthic and planktonic foraminifers in the Suvlukaya section was studied as well (Table 2), and supplemented with other authors' data concerning large benthic foraminifers (Zakrevskaya, 1990; Nemkov and Barkhatova, 1959; *Putevoditel'* ..., 1971) and calcareous nannoplankton (Muzylev, 1980).

Very rare benthic foraminifers *Pararotalia obourgensis, Anomalinoides eogranosa, A. danica* and *A. grandis* were found in the upper part of Bed 1. The foraminiferal assemblage sharply changes in Bed 2. *Gaudryina gigantica, Cibicidoides proprius, C. incognitus*, and *C. succedens* appear here among the benthic foranimifers, and *Globigerina* aff. *nana, G.* aff. *aequensis*, and *Acarinina subsphaerica*, among the planktonic forms.

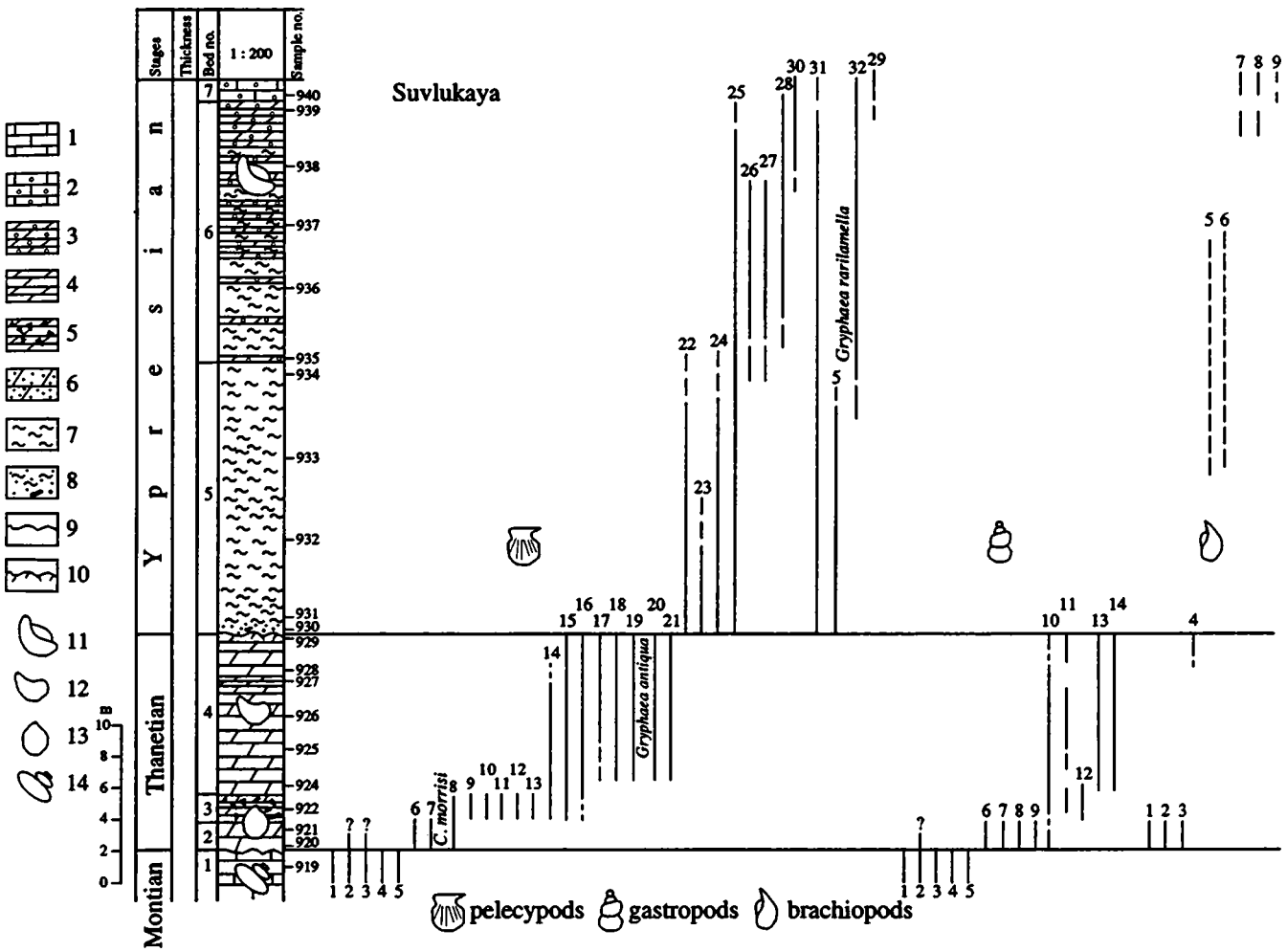

Fig. 2. Distribution of the macrofossils in the Suvlukaya section.

1 – Light-colored, yellowish-pink, hard organogenic limestones; 2 – white massive nummulitic limestones; 3 – light-grey and yellowish-grey nummulitic marls; 4 – massive marls of various tints of grey, partly greyish-yellow; 5 – "sponge horizon" – marls with dark grey silicified concretions substituting sponges (Bed 3); 6 – greenish-grey, sandy, glauconite marls (base of the Bed 2); 7 – brownish-grey and dark grey viscous limy clays (carbonate content increases upwards); 8 – dark greenish-grey and yellowish-grey sandy glauconite clays with rare and large phosphorite concretions (base of the Bed 5); 9 – eroded top of the limestones (Bed 1); 10 – top of the marls (Bed 4) with thalassinoid pores. Characteristic macrofossils: 11 – *Gryphaea rarilamella* valves; 12 – *Gryphaea antiqua* valves; 13 – *Cyprina morrisi* casts; 14 – large gastropod casts.

Table 2. Microfauna of the Suvlukaya section

Number in Fig. 3	Forms	Number in Fig. 3	Forms
	Small benthic foraminifers	24	*N. planulatus* (Lamarck)
1	*Anomalina fera* Schutzkaja	25	*N. pratti* d'Archiac
2	*Cibicides reinholdi* ten Dam	26	*Operculina semiinvoluta* Nemkov et Barchatova
3	*C.* ex gr. *ungerianus* (d'Orbigny)		Planktonic foraminifers
4	*Falsoplanulina subbotinae* (Balakhmatova)	27	*Acarinina acarinata* Subbotinae
5	*Hanzawaia ekblomi* Brotzen	28	*A. convexa* Subbotinae
6	*Heterolepa brata* (Schutzkaja)	29	*A. gravelli* (Bronnimann)
7	*H. libica* (Le Roy)	30	*A. subsphaerica* Subbotina
8	*Pseudogaudryina externa* Bugrova	31	*A. triplex* Subbotina
9	*Uvigerina praecompacta* Balakhmatova	32	*Globigerina compressaeformis* Chalilov
10	*Vaginulinopsis eofragaria* (Balakhmatova)	33	*G. contorta* Schutzkaja
11	*V.* ex gr. *mexicana* Cushman	34	*G. crassa* Schutzkaja
	Larger benthic foraminifers	35	*G. hevensis* Schutzkaja
12	*Assilina laxispira* de La Harpe	36	*G. incisa* Hillebrandt
13	*A. leymeriei* (d'Archiac)	37	*G. nana* Chalilov
14	*A. placentula* Deshayes	38	*G. pileata* Chalilov
15	*A. plana* Schaub	39	*G. quadritriloculinoides* Chalilov
16	*A. pomeroli* Schaub	40	*G. rotundaenana* Schutzkaja
17	*A. pustulosa* Davis	41	*G. velascoensis* Cushman
18	*Nummulites crimensis* Nemkov et Barchatova	42	*Globoconusa chascanona* (Loeblich et Tappan)
19	*N. distans* Deshayes	43	*Globorotalia aequa* Cushman et Renz
20	*N. distans minor* d'Archiac	44	*G. elongata* (Glaessner)
21	*N. irregularis* Deshayes	45	*G. subbotinae* Morozova
22	*N. murchissoni* Brunner	46	*G. wilcoxensis* Cushman et Ponton
23	*N. nitidus* de La Harpe		

The same assemblage of foraminifers and nannoplankton occurs in Bed 3 ("sponge horizon").

Bed 4 contains a taxonomically diverse foraminiferal assemblage. *Cyroidina pontoni, Siphonina prima, Asterigerina nörvangi, Anomalinoides fera, Cibicidoides alleni, Brotzenella acuta, Bulimina rozenkranzi, Globigerina nana, G. pileata, Acarinina acarinata, Globoconusa chascanona, Globorotalia pseudomenardii,* and *G. elongata* are the most characteristic forms of Bed 4.

The foraminiferal assemblage of Bed 5 differs greatly from the previous one (Fig. 3). In fact, it is a new assemblage of benthic foraminifers, which is almost completely lacks species similar to those in the underlying unit. *Pseudogaudryina externa, Vaginulinopsis eofragaria, Falsoplanulina subbotinae, Heterolepa libica,* and *Uvigerina praecompacta* are its most characteristic forms.

The taxonomy of the planktonic foraminifers changes significantly. Various globorotaliids occur in the lowermost part of the bed: *Globorotalia aequa, G. wilcoxensis,* and higher *G. subbotinae, G. marginodentata,* and *Acarinina triplex.*

The appearance of large foraminifers represents another distinctive feature of this assemblage. The most significant among them are *Nummulites crimensis, Operculina semiinvoluta, Assilina pustulosa, A. leymeri, A. pomeroli,* and various *Discocyclina* forms.

Within beds 6 and 7 the amount of small foraminifers gradually decreases upwards. Rare forms typical of clayey Bed 5 are transitional species here. *Acarinina pentacamerata* is a rare representative of the planktonic species. The abundance and diversity of the rock-forming large foraminifers increase in Bed 7. The most significant forms of the lower part of Bed 6 are *Assilina placentula, A. plana, Nummulites planulatus, N. distans minor, N. irregularis, N. murchissoni,* and others. *N. nitidae, N. pratti, Assilina laxispira,* and others are typical of the upper part of Bed 6. In addition to nummulites and assilinids, there are numerous *Discocyclina* forms among large foraminifers.

The suggested foraminiferal zonation (Fig. 3) accords well with the results of former investigations (Bykov, 1971; Zakrevskaya, 1990; Nemkov and Barkhatova, 1959; *Putevoditel'* ..., 1971; Shutskaya, 1970; Yartseva, 1973). However, planktonic units are in need of certain corrections. According to Shutskaya

(1970), the lower part of the marl member corresponds to the *Acarinina tadjikistanensis djanensis* Zone preceding the *A. subsphaerica* Zone. Like Bykov (1971) we did not find the assemblage of the lower zone. Another modernization concerns the *Globorotalia aequa* Zone identified by Shutskaya in the lower part of Bed 5. We consider the assemblages with *Globorotalia aequa* to be constituents of the *G. subbotinae* Zone. The disputable position of the *Globorotalia aequa* Zone in the Crimean sections was indicated in the summary volume on the Stratigraphy of the USSR (*Stratigrafiya* ...,1975).

CORRELATION OF THE SUVLUKAYA AND WESTERN EUROPEAN SECTIONS

The presented data on Suvlukaya microfossils is a summary of the published materials (Vasilenko, 1952; Vyalov, 1976; Zubkovich, 1956; Kovaleva, 1961; *Putevoditel'*..., 1971). In general, we conclude that correlation of the Suvlukaya section with the Thanetian, Ypresian, and Lutetian stages suggested by the previous researches should be retained. Zubkovich (1956), who studied in detail the molluscan fauna from the Crimean marl member, revealed its close relations with the fauna of the Thanetian Stage of the Parisian and Belgian basins, and more loose correlations with that of the England basin. These conclusions are reliable. We also agree with Vasilenko's (1952) opinion that overlying clays are of Ypresian age. Our review of the available new information on the Paleogene stratigraphy in Europe combined with nannoplankton data allows us to define the age of the Suvlukaya biostratigraphic units more accurately.

General information about stratotypes of the Thanetian and Ypresian stages and new data on stratigraphy of the Upper Paleocene and Lower Eocene of Western Europe were discussed in our previous work. Stratotypes of these stages are described in the reference books by Heinzelin and Glibert (1957); Davis (1958)

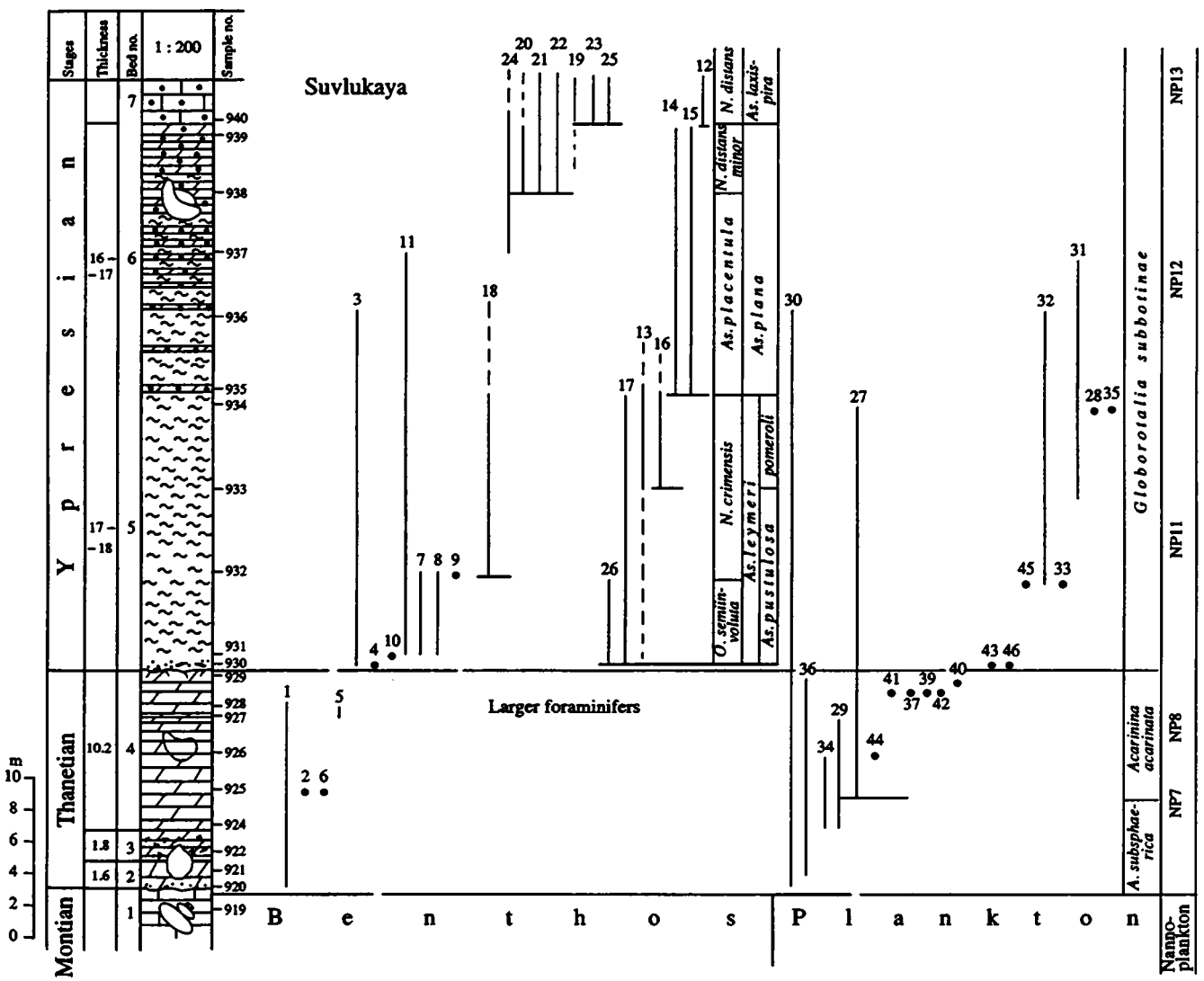

Fig. 3. Distribution of microfossils in the Suvlukaya section. (For symbols see Fig. 2.)

for the Thanetian Stage, and Heinzelin and Glibert (1957); Steurbaut (1987); *Stratotypes* ... (1981) for the Ypresian Stage.

Prestwich (1988) subdivided the Thanetian Stage (the so called "Thanetian sands") into two units corresponding from the top downwards to the *Ostrea belovacina–Pectunculus terebratularis* and *Pholadomya koninkii–Cyprina morrisi* zones. We should mention here one important feature of the stage stratotype (Kent, England): "the Thanetian sands" overlie the Upper Cretaceous deposits.

El-Naggar (1967) identified planktonic foraminifers in the upper part of the "Thanetian sands" of the stratotype area. Among them there are species similar to forms from the marl member of the Suvlukaya section: *Globigerina aequensis, Globorotalia pseudomenardii,* and *Globoconusa chascanona.*

Principal information concerning the Thanetian deposits was obtained in the Belgian and Parisian basins. The main part of the Thanetian stage in Belgium corresponds to the Landen Formation, and the lesser one, to the Heers Formation (Nolf and Steurbaut, 1990; *The Ypresian stratotype*, 1988). Many authors (Robaszynski, 1978; *Stratotype* ..., 1981) still use Leriche's (1903) zonal scheme, which includes, from the top downwards, the sequence of the *Cyprina scutellaria* (the Granglize and Dormal sands), *Pholadomya koninckii* (=*obliterata*) (the Angre and Linsent tuffs), and *Cyprina morrisi* (the Heers Formation) zones.

Lithostratigraphic units (formations, sands, and tuffs corresponding to our formations) are given in brackets. Recently Belgian authors (Nolf and Steurbaut, 1990) identified within the Landen Formation such units as the Erquelinnes and Dormal sands overlying the above sequence of zonal deposits.

Farchad (1936) and Zubkovich (1956) showed that stratigraphic ranges of species defining Leriche's zones are wider. This presents the opportunity to correlate the *Cyprina morrisi* beds and "sponge horizon" with *Pholadomya koninckii* and *Cyprina morrisi* of the Suvlukaya section with the lower zone of Prestwich's scheme and the middle zone of Leriche's scheme. The lower horizons of the Thanetian are absent in both the Crimea and England.

According to mollusks and nummulites, beds 5 and 6 correspond to the Ypresian Stage. The Ypresian molluscan fauna of Western Europe is described in publications. There is no data on mollusks from the stratotype area near the Yeper (Western Flandres). The Yeper Formation comprises the main part of the Ypresian Stage in Belgium (*The Ypresian stratotype*, 1988; Nolf and Steurbaut, 1990). As it was reported (*The Ypresian stratotype*, 1988), new data on the Ypresian mollusks from Belgium is limited. Dhondt (1966) listed 12 pelecypod species from the upper part of the Yeper Formation near Hent. Interlayers with abundant pelecypod, mainly pectinids, remnants are characteristic of interlayers in clays of the middle part of the Yeper Formation in the area to the east of the Yeper (*The Ypresian stratotype*, 1988). Three pectinids species are considered as regional index-fossils: "*Pecten*" *duplicatus* (Sow.), "*Pseudamussium*" sp., and *Lentipecten corneum* (Sow.).

As a whole, clays of beds 5 and 6 resemble clays of the Yeper Formation. Both of them contain interlayers with abundant pelecypod, mainly remnants of pectiniacean. Undoubtedly, a direct correlation based on common species is also possible. Probably, the mentioned *Lentipecten corneum* (Sow.) was determined by Vasilenko to be *Pseudamussium corneum* (Sow.).

The giant oyster *Gryphaea rarilamella*, characteristic of Bed 6 of the Suvlukaya section, is known from different localities of Mangyshlak and Western Europe (Vasilenko, 1952; Dylevskaya, 1913). Feuguer (1963) described sands bearing *Gryphaea rarilamella* in northeastern France (the Laon sands) and southeastern Flandres near Ronse. In Belgium, the Mons-en-Pevele sands in the lower part of the Yeper Formation correspond to the Laon sands. These sands contain *Gryphaea rarilamella* shells. The data on *G. rarilamella* distribution within the sections of the Parisian and Belgian basins suggests that in the Crimea not only layers with *Gryphaea rarilamella* (Bed 6) correspond to the lower part of the Ypresian Stage, but partly the nummulitic limestones with rare *G. rarilamella* shells (Bed 7 and overlying strata in Fig. 2) as well, though the latter are usually included into the Lutetian Stage (Vasilenko, 1952).

In Belgium, the upper part of the marl member, i.e., the *Gryphaea antiqua* beds, corresponds to either the hiatus, or higher horizons of the Landen Formation (see below).

We have shown earlier (Naidin and Ben'yamovskii, 1988) that molluscan assemblages are of great significance in the correlation of the Thanetian sections. *Cyprina morrisi* is known not only in the stratotype locality, but also in the Belgian and Parisian basins, the Caucasus, northern Ukraine, the Volga river region, and Tadjik depression. *Gryphaea antiqua* was found in Poland, Bulgaria, northern Ukraine, Abkhazia, Mangyshlak, Turkmeniya, and the Tadjik depression. In these regions, like in the Crimea, these forms occur at different stratigraphic levels, *Cyprina morrisi* being lower than *Gryphaea antiqua.*

Microfossil assemblages of the Crimea and Western Europe are remarkable in that they have some common features. Foraminiferal assemblages from the Linsent tuffs of the Landen Formation and the marl member (beds 2 - 4) of the Suvlukaya section have common species among benthic forms (*Gyroidina pontoni, Valvulineria ravni, Asterigerina nörvangi, Cibicidoides succedens, C. proprius,* and *Bulimina rosenkrantzi*) and planktonic species (*Globorotalia pseudomenardii*).

The Suvlukaya assemblage of small foraminifers (beds 5 - 7) differs greatly from that of the Yeper Formation. Such genera as *Pararotalia, Elphidium, Cribrononionina, Protoelphidium,* and others absent in the Crimean sections occur in the Belgian basin.

It is rather interesting that *Nummulites planulatus* characteristic of the Crimean sections is also present in clays of the Yeper Formation (*The Ypresian stratotype*, 1988). Apparently, the influence of the Mediterranean water mass upon EPP increased during the Ypresian (Fig. 4). This is confirmed by the appearance and distribution of large thermophilic foraminifers, such as *Nummulites*, *Assilina*, and *Operculina*. An investigator of Crimean nummulitids Shaub (1966) reported that the Bakhchisarai fauna occurs in the sections of the Pyrenees piedmont and southern Alps piedmont, and that deposits bearing larger foraminifers correspond to the Ilerdian and Cuisian stages of the Lower Eocene of the Mediterranean province. The Suvlukaya section and the Cuisian Stage of the Parisian basin contain the common planktonic species *Globorotalia marginodentata*, and *G. subbotinae* together with various nummulites (Bignot, 1981).

In addition mollusks, brachiopods, and foraminifers, other fossils occur in the Suvlukaya section. Panova (1978) revealed that, according to spore and pollen composition, the marl member (beds 2 - 4) can be correlated with the Thanetian Stage, and the clay member (beds 5 and 6) – with the Sparnakian Stage (lower part of the Ypresian Stage) of the Parisian basin.

Calcareous nannofossils are also very important for correlation goals. Several researches studied nannoplankton of the Suvlukaya section (Andreeva-Grigorovich, 1973; Muzylev, 1980; Kapellos, 1973), and Muzylev (1980) obtained the most interesting results. The nannoplankton zones are shown in Fig. 5. The marl member (beds 2 - 4) comprises the entire NP8, and the upper part of the NP7 zones.

According to Aubrey (1986) the Heers Formation in Belgium includes the NP6 and NP7 zones, and the Linsent sands in the lower part of Landen Formation correspond to the NP8 Zone. She also showed that the "Thanetian sands" in the upper part of the Thanetian stratotype (Kent, England) correspond to the NP8 Zone. Currey (*Stratotypes ...*, 1981) found nannofossils of the NP9 Zone in the upper part of the sands.

Figure 6 shows correlation of the nannoplankton zones and lithostratigraphic units of the Upper Paleocene deposits of Belgium and Denmark according to Aubrey's (1986) data.

The nannoplankton data proves that the Suvlukaya marl member corresponds to the Linsent tuffs of the Landen Formation, and this does not contradict the inferred correlation of the Belgian and Crimean units according to bivalves. However, the correlation of the upper part of the marl member (the *Gryphaea antiqua* beds) with the Belgian units is still under question. As for NP zones, the beds correspond to the upper part of Linsent tuffs of the Landen Formation (as shown

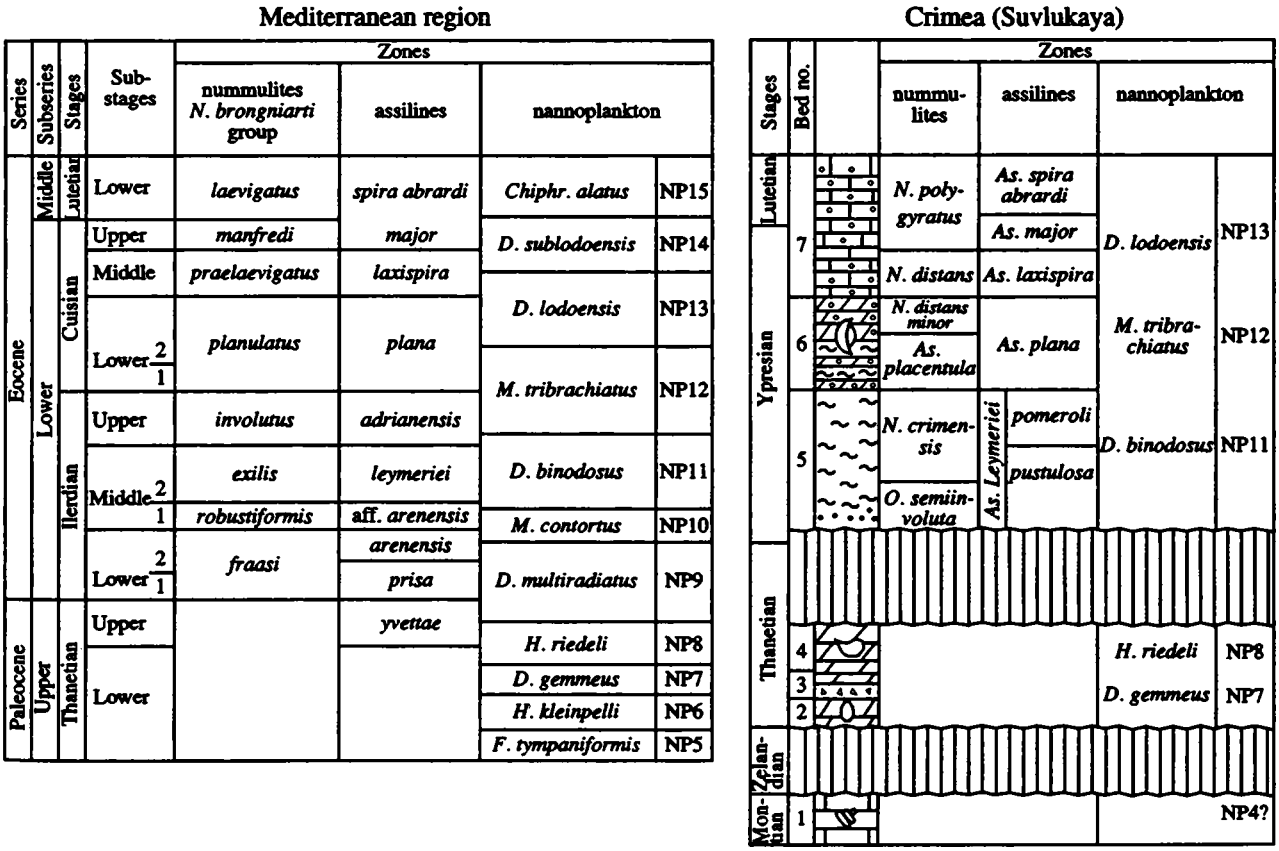

Fig. 4. Comparison of stratigraphic units of the Suvlukaya and Mediterranean sections (Nemkov and Barkhatova, 1959; Zakrevskaya, 1990; Schaub, 1981). For symbols see Fig. 2.

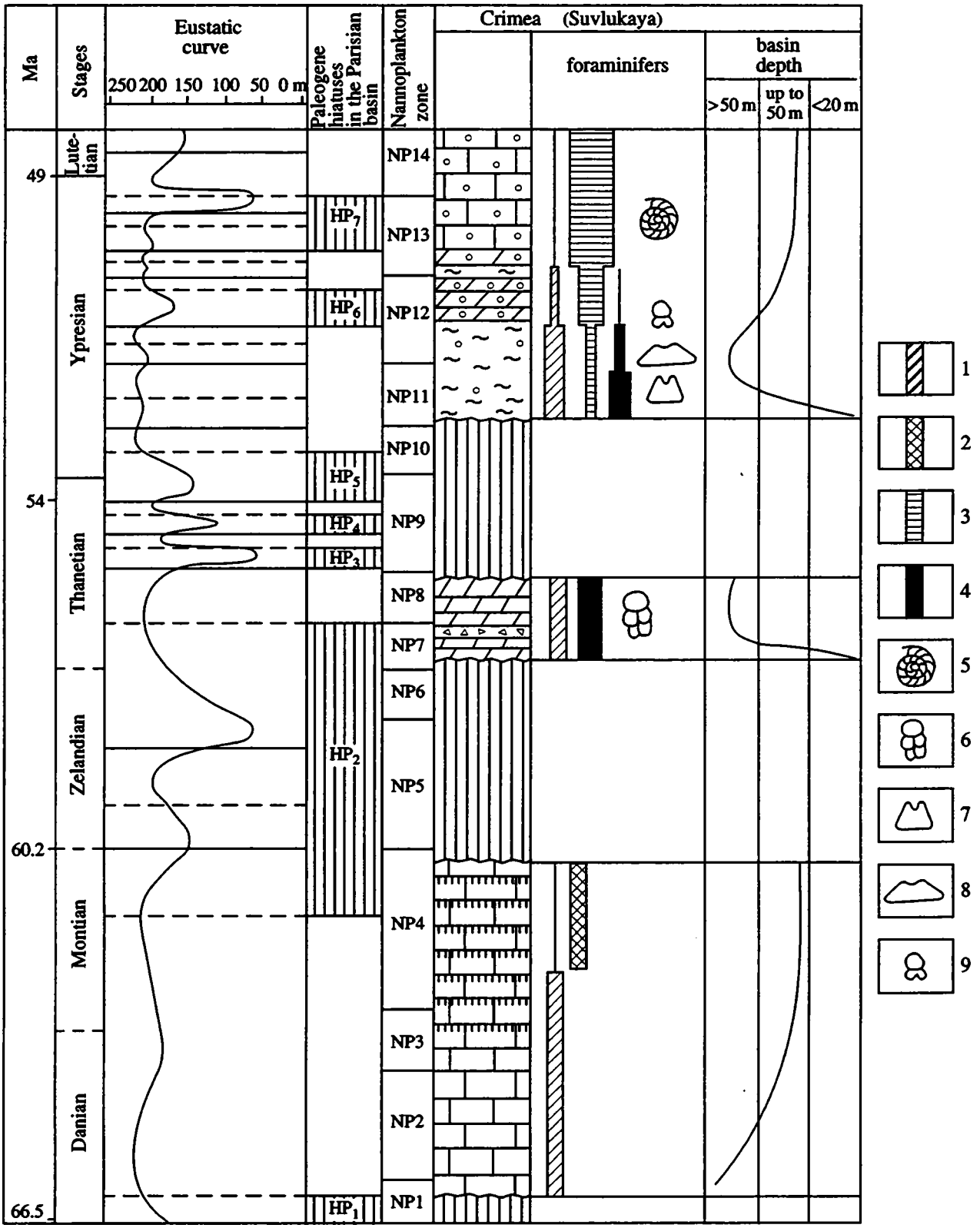

Fig. 5. Correlation of the Suvlukaya section with the eustatic curve and diagram of the Paleocene and Early Eocene hiatuses in the Parisian basin. The left scale (with the Montian and Zelandian) is according to Pomerol (1989).

The lithologic column as in Fig. 2. Foraminifers: 1 – benthic; 2 – tropical benthic of the Montian; 3 – nummulites; 4 – planktonic foraminifers; 5 – larger nummulites (*N. distans*); 6 – akarinins; 7 – box-shaped globorotaliids (*G. aequa*); 8 – low-conical globorotaliids (*G. subbotinae*); 9 – globigerinids. Other symbols as in Fig. 2.

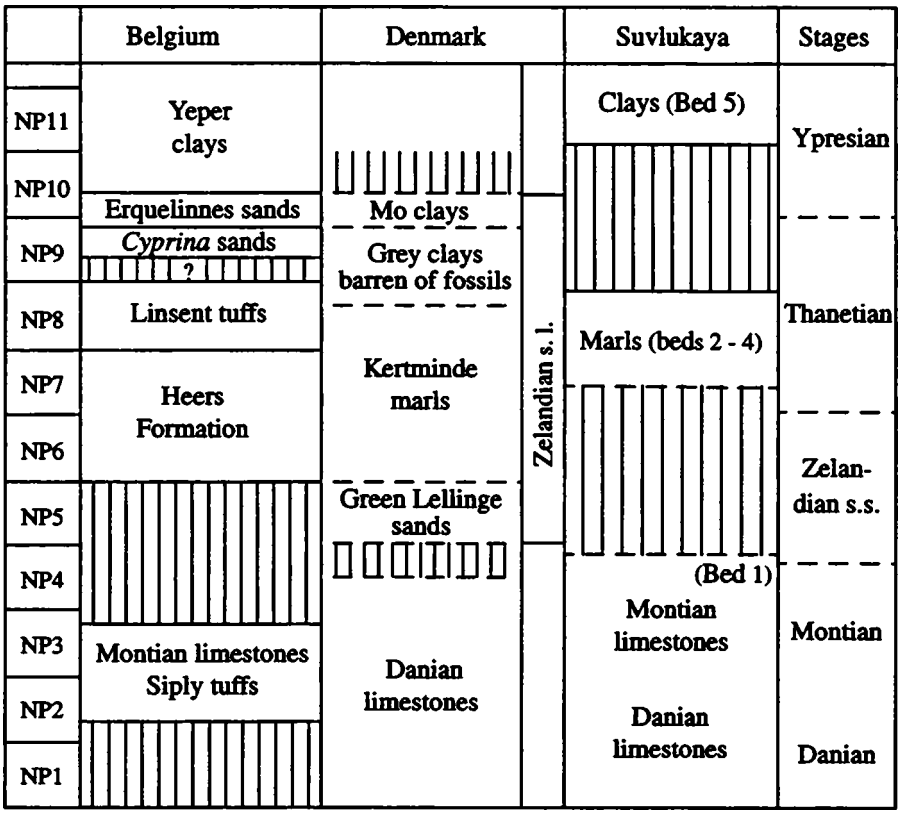

Fig. 6. Nannoplankton zones of the Upper Paleocene in Belgium and Denmark according to Aubrey (1986) and their correlation with the Suvlukaya section.

in Fig. 6). But the *Gryphaea antiqua* beds may be also correlated to the higher horizons of the Landen Formation, or to the hiatus between it and the Heers Formation.

As noted above, the "Thanetian sands" overlie the Upper Cretaceous deposits in the Thanetian stratotype locality. The problem here is where to place the lower boundary of the stage. Earlier we supported the suggested existence of the Zelandian Stage (Naidin and Ben'yamovskii, 1988). But now we think it should be shorter in interval than that suggested by Perch-Nielsen and Hansen (1981). Their Zelandian Stage s.l. includes a considerable part of the Thanetian deposits of the English-French-Belgian provinces. We consider the Zelandian–Thanetian boundary to coincide with the appearance level of the *Cyprina* fauna. In Belgium its position is within the Heers Formation. We think that the upper boundary of the Thanetian coincides with the base of the Yeper Formation of Belgium. So, the Suvlukaya section includes only a small part of the Thanetian deposits slightly truncated from the base, but considerably from the top.

Higher in this section, the nannoplankton zones NP11 and NP12, which comprise the main part of the Yeper Formation (Steurbaut, 1987; *The Ypresian stratotype*, 1981) correspond respectively to the clay unit (Bed 5, the *Pseudamussium corneum* beds) and clays with marl interlayers (Bed 6, the *Gryphaea rarilamella* beds). The NP13 Zone in the Suvlukaya section begins in Bed 7 and includes the overlying nummulitic limestones (they are not indicated in Figs. 2 and 3). In Belgium, this zone covers the upper part of the Yeper Formation and overlying Vliertsele Formation. Belgian authors consider the latter to be of Ypresian age (Nolf and Steurbaut, 1990). So, according to the plankton distribution the Suvlukaya limestones (Bed 7 and overlying strata) usually considered as "Lutetian" have to be correlated with the upper part of the Ypresian stage of Belgium.

The brief description presented here shows the Suvlukaya section to be one of the most important in the sequence system of the so called "Bakhchisarai stratotype," which was suggested to cover significant stratigraphic hiatuses, first, between the Montian limestones (Bed 1) and the Thanetian marl member (beds 2 - 4), and second, between the Thanetian marls and Ypresian clays (Bed 5). Both hiatuses are evident due to sharp compositional changes of rocks and macrofossil assemblages. They are also manifested by minor angular unconformities traceable in the southwestern Crimea.

Foraminiferal and nannofossil data offers the opportunity to estimate the range of these stratigraphic hiatuses. The range of the first one is equal to the eliminated NP5 and NP6 zones corresponding to the Zelandian s.s. The second hiatus between the Thanetian

marls and Ypresian clays had a range of the NP9 and NP10 zones.

So, both the upper part of the Thanetian and lower horizons of the Ypresian are absent in the section. The absence of the latter is proven by the radiometric datings of glauconites from the base of the Ypresian of the Bakhchisarai region (Bed 5: 51.5 ± 1.5 and 49.7 ± 0.9 Ma) (Barkhatova and Sprintson, 1973). These age values are younger than those for the base of the Ypresian stratotype: 57.7 Ma (Berggren *et al.*, 1985), 56.5 Ma (Harland *et al.*, 1989), and 54 Ma (Pomerol, 1989; Haq *et al.*, 1987).

CONCLUSION

(1) We disagree with those scientists who considered stratotypes of the Thanetian and Ypresian stages of the Paleogene to be useless in the elaboration of standard units. This misinterpretation resulted in the appearance of the "Bakhchisarai stratotype section." Recently, foreign scientists considerably enlarged and obtained more precise data on stratotypes of various Paleocene and Eocene stages. We used these data for stratigraphic "calibration" of the Suvlukaya section.

(2) We consider the study of the reference sections to be necessary for remote correlations. The Suvlakaya section can be suggested as one of the reference sections for the Paleogene, though there are considerable hiatuses in it. The coexistence of fossils of the European and Mediterranean paleobiogeographic provinces makes the Suvlukaya section especially valuable.

Reviewer Yu. B. Gladenkov

REFERENCES

Andreeva-Grigorovich, A.S., Nannoplankton Zonal Subdivisions of the Paleogene Deposits near Bakhchisarai, *Dokl. Ukr. Akad. Nauk*, 1973, B, no 3, pp. 195 - 197.

Aubry, M.P., Paleocene Calcareous Nannoplankton Biostratigraphy of Northwestern Europe, *Palaeogeogr., Palaeoclim., Palaeoecol.*, 1986, vol. 55, nos. 2 - 4, pp. 267 - 334.

Barkhatova, N.N. and Sprintson, V.D., The Radiometric Age of the Lower Eocene Deposits of the Bakhchisarai Section of the Crimea, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1973, no. 3, pp. 130 - 131.

Berggren, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., Cenozoic Geochronology, *Bull. Geol. Soc. Am.*, 1985, vol. 96, pp. 1407 - 1418.

Bogmot, G., Cuisian, Stratotypes of Paleogene Stages, *Bull. d'Inform. Geol. Basc.*, 1981, Paris, mem. hore serie, no. 2, pp. 63 - 75.

Bykov, V.F., Distribution of the Small Foraminifers in the Paleocene–Eocene Deposits of the Bakhchisarai Section, *Tr. VNIIGAZ* (Publ. of the All-Union Scientific Research Gas Institute), 1971, vols. 31/39, 32/40, pp. 83 - 85.

Cavelier, G. and Pomerol, C., Stratigraphy of the Paleogene, *Bull. Soc. Geol. France*, 1986, ser. 7, vol. 11, no. 2, pp. 255 - 265.

Davis, A.G., Thanet Sands (Beds), *Lexique Stratigr. Intern. Europe*, 1958, vol. 1, p. 73.

De Gevter, G., The Landen Formation, *Bull. Soc. Belge Geol.*, 1987, vol. 96, no. 4, pp. 353 - 356.

Dhondt, A., Mollusken. Hed Fossielhoudend Ieperian van Merelneke, *Naturvet. Tijdschr.* (Gent), 1966, vol. 48, pp. 218 - 220.

Dylevskaya, A.N., *Ostrea rarilamella* from the Lower Tertiary Deposits of the Mangyshlak, *Zapiski Kievskogo Obshch. Estestvoispytatelei*, 1913, vol. 23, no. 1, pp. 143 - 150.

El-Naggar, Z.R., Planktonic Foraminifera in the Thanet Sands of England and the Position of the Thanetian in Paleocene Stratigraphy, *J. Paleontology*, 1967, vol. 41, no. 3, pp. 575 - 587.

Farchad, H., Etude de Thanetian (Landenien marin) du bassin de Paris, *Mem. Soc. Geol. France*, 1936, mem. 30, pp. 1 - 103.

Feuguer, L., L'Ypresian du bassin de Paris, *Mem. Serv. Carte Geol. France*, Paris, 1963.

Harland, W.B., Armstrong, R.L., Cox, A.V., Graid, E.L., Smith, A.G., and Smith, D.G., *A Geologic Time Scale, 1989*, Cambr. Univ., 1989.

Heinzelin, de J. and Glibert, M., Landenien, *Lexique Stratigr. Intern. Europe*, 1957, vol. 1, Fasc. 4aVII, pp. 99 - 101.

Heinzelin, de J. and Glibert, M., Ypresien, *Lexique stratigr. intern. Europe*, 1957, vol. 1, Fasc. 4aVII, pp. 205 - 208.

Kappelos, C., Biostratigraphie des Gurnigelflysches, *Schweiz. Palaontol.*, 1973, vol. 96, pp. 1 - 128.

Kovaleva, N.P., New Data on Brachiopod Taxonomy of the Lower Paleogene Deposits of the Crimea (Bakhchisarai Region) and Transcaucasian Area (Sukhumi Region), *Dokl. Akad. Nauk SSSR*, 1961, vol. 136, no. 3, pp. 686 - 688.

Lange, O.K. and Mirchink, G.F., About the Upper Cretaceous and Tertiary Deposits of the Bakhchisarai Region, *Byull. MOIP (Protokoly)*, 1909 (1910), pp. 36 - 42.

Leonov, G.P., Some Aspects of the Problem on the Paleogene Subdivision into Stages, *Vestn. Mos. Gos. Univ., Ser. Geol.*, 1963, no. 4, pp. 34 - 35.

Leonov, G.P., Alimarina, V.P., and Naidin, D.P., About the Principles and Methods of Marking out Stages of the Standard Scale, *Vestn. Mos. Gos. Univ., Ser. Geol.*, 1965, no. 4, pp. 15 - 28.

Leriche, M., Sur les horizons paleontologiques du Landenien marin du Nord de la France, *Ann. Soc. Geol. Nord.*, 1903, vol. 32, pp. 234 - 252.

Menner, V.V., The Paleogene Stage Scale Based on the Bakhchisarai Section of the Crimea, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1983, no. 11, pp. 5 - 11.

Muratov, M.V. and Nemkov, G.I., Paleogene Deposits of the Bakhchisarai Region and Their Significance for Stratigraphy of the Paleogene of the Southern USSR, *Paleogenovye Otlozheniya Yuga Evropeiskoi Chasti SSSR* (Paleogene Deposits of the South European Part of the USSR), Moscow: Akad. Nauk SSSR, 1960, pp. 15 - 23.

Muratov, M.V. and Nemkov, G.I., Stratigraphy of the Crimean Paleogene Deposits as a Basement for Stratigraphic Subdivision of the Paleogene in the USSR, *Trudy Soveshchaniya po Razrabotke Unifitsirovannoy Stratigraficheskoi Shkaly Tretichnykh Otlozhenii Yuga Evropeiskoi Chasti SSSR* (Proc. Conf. on Elaboration of Unified Stratigraphic Scale for Tertiary Deposits of South European USSR), Baku: Inst. Geol. Azerb. Akad. Nauk, 1959, pp. 57 - 63.

Muzylev, N.G., Nannoplankton Stratigraphy of the Paleogene of the Southern USSR, *Tr. Geol. Inst. Akad. Nauk SSSR*

(Proc. Geol. Inst., USSR Acad. Sci.), Moscow: Nauka, 1980, vol. 348.

Naidin, D.P. and Ben'yamovskii, V.N., About the Upper Limit of the Danian. Stratotypes of the Paleocene Stages, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1988, no. 10, pp. 3 - 15.

Naidin, D.P. and Ben'yamovskii, V.N., About the Upper Limit of the Danian. The Danian, Montian, and Zelandian Outside the Stratotypic Areas, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1988, no. 10, pp. 3 - 15; 1989, no. 1, pp. 21 - 38.

Nemkov, G.I. and Barkhatova, N.N., Larger Foraminifers Zones of the Crimean Eocene Deposits, *Vestn. Len. Gos. Univ., Ser. Geol. Geogr.*, 1959, vol. 2, pp. 121 - 125.

Nemkov, G.I. and Barkhatova, N.N., Nummulites, Assilines and Operculines of the Crimea, *Tr. Geol. Muzeya im. A.P. Karpinskogo* (Publ. A. P. Karpinskii Geol. Museum), 1961, vol. 5, p. 148.

Nolf, D. and Steurbaut, E., Stratigraphie de l'Eocene en Flandre occidentale et dans les regions limitrouphes, *Bull. Inform. Geol. Bassin Paris*, 1990, vol. 27, no. 3, pp. 9 - 36.

Panova, L.A., Distribution of Spores and Pollen in the Paleogene Deposits of the Bakhchisarai Stratotype Section, *Stratigrafiya Kainozoya Sev. Prichernomor'ya i Kryma* (Cenozoic Stratigraphy of the Northern Black Sea Region and Crimea), Dnepropetrovsk: NIIGeologiya, Dnepr. Gos. Univ., 1978, vol. 2, pp. 69 - 80.

Perch-Nielsen, K. and Hansen, J.N., Zelandian. Stratotypes of Paleogene Stages, Pomerol, C., Ed., *Bull. Inform. Geol. Bassin Paris. Mem. Ser.*, 1981, no. 2, pp. 218 - 230.

Pomerol, C., Stratigraphy of the Palaeogene: Hiatuses and Transition, *Proc. Geol. Ass. London*, 1989, vol. 100, Part 3, pp. 313 - 324.

Prestwich, J., Further Observations on the Correlation of the Eocene Strata in England, Belgium and the North of France, *Quart. J. Geol. Ass. London*, 1988, vol. 44, pp. 88 - 111.

Putevoditel' Ekskursii, Chast' I, Krym (Excursion Guide, XII European Micropaleontological Colloquium, Part 1, Crimea), Moscow: Mos. Gos. Univ., 1971.

Resolutions of the Permanent Stratigraphic Commission of the Interdepartmental Stratigraphic Committee (ISC) on the Paleogene of the USSR, 1962, *Sov. Geol.*, 1963, no. 4, pp. 145 - 154.

Resolutions of the XV Plenary Meet. of the Paleogene Commission, *Postanovleniya MSK i Ego Postoyannykh Komissii* (Resolutions of the Int. Strat. Com. and Its Permanent Commissions), All-Union Geol. Inst. (VSEGEI), 1983, vol. 41, pp. 42 - 44.

Robaszynski, F., Paleocene et Eocene interieur de la region de Mons et du Nord de la France: arguments actuels de correlation, *Bull. Soc. Belge Geol.*, 1978, vol. 87, no. 4, pp. 239 - 247.

Schaub, H., Nummulites et assilines de la Tethys Paleogene. Taxonomie, phylogenese et Biostratigraphie, *Schweiz. Paläontol. Abhand. Mem. Suis Paleont.*, 1981, vol. 104, p. 236.

Shaub, G., Nummulite Zones and Evolutionary Lines of Nummulites and Assilines, *Voprosy Mikropaleontologii*, 1966, vol. 10, pp. 289 - 302.

Shutskaya, E.K., Stratigraphy, Foraminifers and Paleogeography of the Lower Paleogene of the Crimea, Cis-Caucasian Region and Western Middle Asia, *Tr. VNIGNI* (Publ. of the All-Union Sci.-Res. Geol.-Prospecting Oil Inst.), 1970, vol. 70.

Steurbaut, E., The Ypresian in the Belgian Basin, *Bull. Soc. Belge Geol.*, 1987, vol. 96, pp. 339 - 351.

Stratigrafiya SSSR. Paleogenovaya Sistema (Stratigraphy of the USSR. The Paleogene System) Moscow: Nedra, 1975.

Stratotypes of Paleogene Stages, Pomerol, C., Ed., *Bull. Inform. Geol. Basin Paris. Mem. Ser. 2*, 1981, p. 301.

The Ypresian Stratotype, Dupuis, C., Deconinck, J., and Steurbaut, E., Eds., *Bull. Soc. Belge Geol.*, 1988, vol. 97, nos. 3, 4, p. 481.

Vasilenko, V.K., Stratigraphy and Molluskan Fauna of the Eocene Deposits of the Crimea, *Tr. VNIGRI* (Publ. of the All-Union Oil Sci.-Res. Geol.-Prosp. Inst.), Nov. Ser., 1952, vol. 59, p. 128.

Vyalov, O.S., Bakhchisarai Paleogene Section, The Main Paleocene Exposures, *Geol. Geokhim. Goryuchikh Iskopaemykh*, 1976, vol. 47, pp. 80 - 88.

Vyalov, O.S., The Main Eocene and Oligocene Sections, *Geol. Geokhim. Goryuchikh Iskopaemykh*, 1977, vol. 48, pp. 93 - 102.

Yartseva, M.V., Characteristics of the Benthic Foraminiferal Assemblages of the Paleocene Stratotype Sections of the Bakhchisarai Region, *Tektonika i Stratigrafiya*, 1973, no. 6, pp. 33 - 40.

Zakrevskaya, E.Yu., *Assilina operkulina* and *Renikotalia* Forms from the Crimea and Their Significance for the Eocene Stratigraphy, *Cand. Sci. (Geol.-Min.) Dissertation*, Moscow: Moscow Geol. Prospecting Inst., 1990.

Zhizhchenko, B.P., *K Probleme Yarusnogo Deleniya Paleogenovykh Otlozhenii Yuga Sovetskogo Soyuza* (Some Aspects of the Subdivision of Paleogene Deposits into Stages in the Southern USSR), Moscow: VNIIGAZ, 1965.

Zubkovich, M.E., Stratigraphy of the Thanetian in the Western Crimea, *Dokl. Akad. Nauk SSSR*, 1956, vol. 108, no. 5, pp. 920 - 922.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 284 - 288. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 87 - 91.
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Isotopic Dating of Paleogene and Neogene Volcanogenic Sequences of Kamchatka

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Abstract – Isotopic datings of volcanites from a number of areas of the western coast of Kamchatka, where volcanogenic sequences overlie or underlie formations with faunal or floral remains, are given in this paper. Radiological determinations often coincide with biostratigraphic data or, at least, do not contradict them. Conspicuous discrepancies may be the result of laboratory errors or geological misinterpretations. Difficulties in the radiometric dating of volcanogenic sequences often formed by united complexes of various ages are discussed. Further studies in this direction during complex geological investigations are judged to be advantageous.

Recent biostratigraphic studies of the Cenozoic in Kamchatka and adjacent regions have yielded data that allowed the recognition of a number of regional stratigraphic units (regional stages and local zones) and the correlation of them with the stages and zones of the general scale.

Unfortunately, there were no special radiometric datings for the Paleogene and Neogene sequences of Kamchatka, and the published ages that were determined only by the K-Ar method were not proven by biostratigraphic data. In this paper, the K-Ar ages of the samples from reliable stratigraphic positions are presented and compared with the ages of the rocks determined by biostratigraphic methods. The isotopic ages were determined using bulk volcanite samples collected by Gladenkov and Shantser.

All the samples were processed in the Laboratory of Absolute Age, Armenian Academy of Sciences, under the supervision of Bagdasaryan, using the standard technique. First, a bulk sample was grinded in a crusher to a grain size of 0.5 mm and then sifted; a 0.5 - 0.25-mm fraction was quarted using the Jones divider to a weighted portion of 10 - 15 g. A small portion was abraded in an agate mortar in order to determine the K content. The rest of the fraction 0.5 - 0.25 mm in size was melted in a metallic reactor to yield Ar. The weighted sample was from 0.5 to 1.0 g. The $^{40}Ar_{rad}$ content was determined by isotopic dilution, Ar rich in ^{38}Ar up to 95% being used as a tracer. To dose the indicator, a dosing apparatus was attached to the conventional Khlopin–Gerling device, which sampled aliquots of the tracer diluted in CO_2. The dilution coefficient (the share of ^{38}Ar in a $^{38}Ar + CO_2$ mixture) was determined by a special series of experiments using the dilution method, under the control of the reference sample "Asia"-1/65, as decreed by the Commission of Isotopic Geology and Geochronology, Russian Academy of Sciences. The control was carried out after each 10 series of K-Ar age determinations. The dosed tracer was precisely measured beforehand in the McLeod manometer and then introduced after melting the sample and transferring the escaped gases to the measuring block of the device.

Isotopic $^{36}Ar/^{40}Ar$ ratios were measured by the two-beam compensation method using a triple-slotted two-collector ion receiver designed in the Institute of Ore Deposits (IGEM), Russian Academy of Sciences. The determination error based on the reproducibility of parallel measurement results was ±2 to 3%. The K content in the samples was determined by the flame-photometric method. As a rule, each sample was subjected to two parallel analyses, an average value being used during the subsequent calculations. The discrepancy between the results of the analyses did not exceed 1.5 - 2.5%, which, the experimental error of measuring of Ar taken into account, yielded a 4 - 5% age-determination error. The ^{40}K decay constants recommended by the International Subcommission on Geochronology in 1976 were used during the age determination. All the age determinations were done with the mass-spectrometer MI-1201 produced by the Elektron Sumy Industrial Association.

The results of the isotopic-geochronological studies are given in the table.

The samples for isotope analysis were collected from the Kamchatka volcanites (only the least altered varieties were considered suitable for the purpose) overlain or underlain by rock sequences that were dated based on faunal or floral assemblages. In most cases, the K-Ar data correspond to the biostratigraphic data,

The results of the K-Ar isotopic-geochronological study of the samples

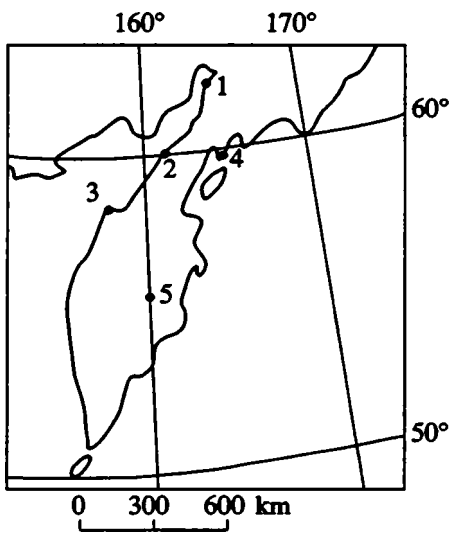
Sample numbers	K content (%)	$^{40}Ar_{rad}$ (%)	^{40}Ar $cm^3\ g^{-1}\ 10^{-6}$	Mean age, Ma	Sample numbers	K content (%)	$^{40}Ar_{rad}$ (%)	^{40}Ar $cm^3\ g^{-1}\ 10^{-6}$	Mean age, Ma
	2.33	–	0.497		3082-5	1.59	25.0	3.18	46.7 ± 2.7
7159	2.33	–	0.46	5.5 ± 0.33		1.59	15.3	2.81	
	2.33	–	0.53		3182	1.92	42.0	4.00	52.7 ± 1.6
	0.93	–	0.16			1.92	42.0	3.97	
7315		–	0.27	5.6 ± 1.1		1.57	14.9	2.77	
	1.64	–	0.386		8142-1	1.57	11.89	2.60	44 ± 2.5
7319	1.64	–	0.368	5.9 ± 0.25		1.57	24.00	2.60	
	1.37	13.80	2.55			1.57	16.90	2.51	
1288-3	1.37	03.68	2.75	49.0 ± 1.9		1.26	18.0	2.38	
0788	1.48	–	0.71	37.4 ± 0.6	8137-22K	1.26	18.0	2.51	49.4 ± 0.9
	1.48	–	0.66			1.26	15.0	2.47	
0888	0.91	5.0	1.39	43.5 ± 4.7		0.94	13.0	1.91	
	0.91	5.0	1.72		10-75	0.94	15.0	1.69	48.3 ± 4.3
	0.63	2.75	1.08			0.94	10.0	1.55	
0388	0.63	2.05	1.02	41.3 ± 1.3		1.13	15.0	2.13	
	0.63	1.90	0.96		0384-1	1.13	13.5	1.91	46.6 ± 2.1
0388-1	3.19	14.0	6.49	53 ± 1.4		1.13	15.8	2.20	
0888-6	0.98	13.0	2.22	57.4 ± 0		1.13	14.0	2.05	
	0.98	13.0	2.22		5	1.01	13.0	1.96	48.4 ± 1
	1.38	7.0	2.40			1.01	9.0	1.88	
0588	1.38	6.0	2.52	46.5 ± 0.5	6	1.4	14	2.29	49 ± 2.25
	1.38	6.65	2.57			1.4	11	2.10	
0788	1.43	20.26	2.70	46.3 ± 1.6	7	1.38	13.0	2.37	47 ± 3.3
	1.43	18.20	2.52			1.38	15.0	2.74	
	1.59	19.0	2.78			1.59	24.01	3.09	
3082-5	1.59	16.8	2.74	46.7 ± 2.7	8	1.59	13.87	3.14	48.7 ± 1.3
	1.59	25.0	3.18			1.59	16.0	2.93	
	1.59	15.3	2.81			0.56	1.51	1.10	
	1.92	42.0	3.61		8a	0.56	2.95	1.14	49.2 ± 1.8
3182	1.92	40.0	3.41	46.0 ± 1.23		0.56	5.0	1.03	
	1.92	38.7	3.36			1.25	18.0	2.43	
	1.57	14.9	2.77		10	1.25	15.46	2.51	49.9 ± 0.8
8142-1	1.57	24.0	2.96	46.3 ± 1		1.25	15.06	2.42	
	1.57	16.9	2.84			1.42	13.0	2.47	
	1.26	18.0	2.38		11	1.42	13.4	2.47	45.2 ± 1.1
8137-22A	1.26	18.0	2.35	47.5 ± 0.44		1.42	15.0	2.60	
	1.26	15	2.31			0.64	3.68	1.28	
	1.73	18.0	3.24		13	0.64	2.80	1.19	47.3 ± 1.0
0384-2	1.73	19.9	3.17	47.5 ± 0.4	14	1.10	17.0	2.03	48.7 ± 1.7
	1.73	21.9	3.23			1.10	15.0	2.18	
	0.94	10	1.73			0.92	12.0	1.78	
1075	0.94	15	1.69	46.9 ± 0.7	15	0.92	13.0	1.84	49 ± 1.25
	0.94	13	1.76			0.92	12.0	1.76	
	1.13	15.0	2.13		16	0.73	4.6	1.51	50.2 ± 2.2
1-79	1.13	13.45	1.91	46.8 ± 2.6		0.73	4.2	1.38	
	1.13	15.8	2.20		100/1	0.76	5.0	1.49	48.5 ± 1.5
	1.13	14.0	2.05			0.76	3.0	1.41	
0384-1	1.13	15.0	2.13	47.0 ± 0.7	100/2	1.20	14.0	2.35	51.3 ± 1.6
	1.13	13.9	2.09			1.20	16.0	2.50	
	1.59	19.0	2.78						

but in some cases there are series of the former that contradict the latter.

The majority of the datings were obtained for the Paleogene sections of western and northeastern Kamchatka. Some datings refer to the Paleogene rocks of central Kamchatka and to the Neogene rocks of eastern and northeastern Kamchatka. The average K content in the rocks is 1 - 1.5%.

A detailed description of faunal and floral remains in the sections is omitted here because they have already been published (Gladenkov *et al.*, 1985; Gladenkov *et al.*, 1990, 1988, 1991; Chelebaeva and Shantser, 1988). Brief geological characteristics of several areas of western Kamchatka from locations where pertinent samples were collected follow (the figure).

The southeast coast of Penzhina Inlet (from the Pustaya River in the north to the mouth of the Shamanka River in the south). The oldest Paleogene sequences here belong to the Chemurnaut Group (the Getkilnin, Kamchik, and Tkapravayam formations), dated as Late Danian–Late Paleocene (the Late Eocene?) by microfauna and leaf flora. The Chemurnaut Group is represented by terrigenous and volcano-terrigenous sediments of the regressive cycle from pure marine facies (the Getkilnin Group) to coastal-marine and continental facies (the Kamchik and Tkapravayam formations). In the group section, numerous sills up to 20 - 30 m thick and intruding dykes of basalts, andesite-dacites, and liparites occur. Structurally, some thick stratiform bodies can be regarded as diorite-porphyrites and grano-diorite-porphyry. The Chemurnaut Group deposits are overlain unconformably by a rock sequence of on-land volcanites of contrasting composition (basalts dominate), which are known as the Velolnyk Formation and the Bozhedomov Formation in the north and south of the area, respectively. The sequence is formed by alternating lava members, basaltic and dacitic in composition, and agglomerate tuffs (psephitic and psammitic tuffs are rare), as well as volcanogenic alluvial-proluvial deposits and lahars. The Bozhedomov Formation incorporates flora typical of the Middle Eocene. The Bozhedomov Formation is overlain by the Irgirnin and Rategin formations characterized by Upper Eocene fauna and flora. Both intrusives of the Chemurnaut Group and volcanites of the Bozhedomov Formation are mostly represented by calc-alkaline rocks. The K content in sills and dykes ranges from 0.56 to 1.59%, the content in the lava flows ranges from 0.72 to 1.92%.



The areas of Kamchatka from which samples of volcanic rocks for isotopic datings were collected.

1 – Southeast coast of Penzhina Inlet; 2 – east coast of Shelekhov Bay; 3 – Utkholokskii Peninsula; 4 – Il'pinskii Peninsula; 5 – Valaginskii Ridge.

The ages (Ma) determined for the sill rocks of the Chemurnaut Group are as follows: 48.4 ± 1 (Sample 5), 49 ± 2.25 (Sample 6), 47 ± 3.3 (Sample 7), 48.7 ± 3 (Sample 8), 49.2 ± 1.8 (Sample 8a), 49.9 ± 0.8 (Sample 10), 45 ± 1.1 (Sample 11), and 47 ± 1.6 (Sample 13). Five samples collected from lavas at different levels of the volcanogenic Bozhedomov Formation outcropping between the Chemurnaut Bay and Cape Rebro revealed ages (Ma) of 48.7 ± 1.7 (Sample 14), 49 ± 1.25 (Sample 15), 50.2 ± 2.2 (Sample 16), 48.5 ± 1.5 (Sample 100/1), and 51.3 + 1.6 (Sample 100/2). The age (Ma) of lavas from the coast between Cape Bozhedomov to the mouth of the Shamanka River was determined for 4 samples, yielding values of 46.7 ± 2.7 (Sample 3082-5), and 52.7 ± 1.6 (Sample 3182); a repeated determination using the first sample showed the same value. Thus, the ages of both intrusives of the Chemurnaut Group and lavas of the Bozhedomov Formation range from 50 to 47 Ma and from 51 to 46 Ma, respectively. All the age values are within the Middle Eocene time interval (the Lutetian and Bartonian stages), rare outsiders indicate the upper portion of the Lower Eocene. Similar ages and compositions of the intrusive and effusive facies allow us to combine them into a single Middle Eocene volcano-plutonic formation.

In the northern area of Cape Bol'shoi, the Getkilnin Formation underlies the basalts of the Velolnyk Formation, the tephritoids of which contain scarce flora considered to be of Oligocene age by some botanists. The 48.3 ± 4.3 Ma (Sample 10-75) and 46.8 ± 2.6 Ma (Sample 1-79) ages for volcanites, however, sharply contradict these views; a repeated determination for Sample 10-75 yielded 46.9 ± 0.7 Ma. In our view, the similarity of compositions and the coincidence of the distribution areas of the volcanites at Cape Bol'shoi and of the Bozhedomov Formation suggest a single Middle Eocene volcanogenic complex.

The fact that the flora-containing lens may refer to a relatively younger volcanogenic sequence included into the basalts at the Cape Bol'shoi should not be ignored.

The eastern coast of Shelekhov Bay from Cape Kinkil' in the north to Cape Kakhtaninskii in the south. Here, at the mouth of the Anadyrka River, Cretaceous sequences are unconformably overlain by the terrigenous Anadyrka Formation, which consists predomi-

nantly of the continental facies. Dacitic ignimbrites occur in the upper portion of the section. The Anadyrka Formation is, in turn, overlain unconformably by the Ust'-Anadyrka Formation composed of terrigenous coastal-marine and continental coal-bearing deposits. Floral assemblages in the former formation and planktonic foraminifers, as well as floral fossils in the latter, refer them to the Paleocene and the Middle Eocene (the Lutetian Stage), respectively (Serova, 1969). Both Cretaceous and Paleocene terrigenous sequences are overlain by a sequence of on-land volcanites (the Kinkil' Formation) composed of calc-alkaline lavas and pyroclastics of predominantly basic composition. Geological survey data shows that in the Palana River basin, the Kinkil' volcanites underlie Upper Eocene–Oligocene sequences of the Amanina–Gakkh Horizon. Contact between the Ust'-Anadyrka and Kinkil' formations has not yet been observed. In the south (Cape Kakhtaninskii), the Kakhtaninskii basalt-dacite sequence unconformably underlies the Middle Eocene coastal-marine facies of the Snatol' Formation. Samples for radiological dating were collected from the Kakhtaninskii volcanogenic sequence, from the ignimbrites of the upper portion of the Anadyrka Formation, and from the Kinkil' volcanites. The measured radiological ages are 49.0 ± 1.9 Ma for the Kakhtaninskii Formation (Sample 1288-3, the K content is 1.37%), 53 ± 1.4 Ma for the ignimbrite of the Anadyrka Formation (Sample 0388-1, the K content is 3.19%), and 37.4 ± 0.6 Ma, 43.5 ± 4.7 Ma, 41.3 ± 1.3 Ma, 46.5 ± 0.3 Ma, and 46.3 ± 1.6 Ma for the Kinkil' Formation (Samples 0788, 0888, 0388, 0588, and 0788, the K content is 1.43 - 0.48%). The figures show that the Anadyrka ignimbrites and the Kakhtaninskii dacites are dated as the Early Eocene (unfortunately, these are single datings). The Kinkil' volcanites demonstrate a wide age range within the Middle-Late Eocene.

The Utkholokskii Peninsula (Western Kamchatka). Along the coast, a sequence of on-land calc-alkaline volcanites occur and andesites (effusives and pyroclastics) dominate. The volcanites conformably underlie a continental terrigenous sequence (the Mys Zubchatyi Formation) characterized by Early Paleocene flora (Chelebaeva and Shantser, 1988). The ages determined for 4 samples (the K content is 1.13 - 2.06%) are 47.5 ± 0.4 Ma (Sample 0384-2), 47.0 ± 0.7 Ma (Sample 0384-1), 46.6 ± 2.1 Ma (Sample 0384-1), and 45.2 ± 2 Ma (Sample 1384-2). It should be noted that two specimens from one sample (0384-1) yielded values differing by more than a million years. The whole series of determinations is within the Middle Eocene, which does not correspond to biostratigraphic data because, judging by the floral assemblages, the overlying formation cannot be younger than the Paleocene. The ages of the same volcanites (?) determined at the laboratory of the Aerogeologiya Scientific Industrial Association referred them rather conclusively to the Danian (Tsukernik, personal communication). The discrepancy between the ages of our samples and biostratigraphic data may be due to several factors: calculation error, secondary alterations in the rocks, causing an escape of radiogenic Ar or introduction of K, and the presence in the area of both Paleocene and Eocene volcanites that could not be distinguished from each other during mapping because of their compositional similarity.

The Il'pinskii Peninsula (Northeastern Kamchatka). The isotopic ages for the area have been published (Gladenkov *et al.*, 1988). Here, we would like to mention only that the ages imply the presence of Paleocene and Early Eocene volcanites in the Cenozoic cross section of the Il'pinskii Peninsula.

The Valaginskii Ridge (Eastern Kamchatka). Two series of pre- and post-thrust intruding and sheeted dykes (diorite-porphyrites and granodiorite-porphyry) are recorded here in Late Neogene deposits (the Shapin Formation) overthrust by the Vetlovaya Paleocene–Eocene sequence. A single dating of 4 Ma for the sheeted dykes water was previously determined at IGEM. Naturally, we were curious to know the age of the dykes intruding a part of the Neogene section and bordered by the thrust zone from above. The determination for one granodiorite-porphyry sample yielded an age of 5.9 ± 0.25 Ma. That ascribes the movement along the thrust to the 4 - 5.9 Ma time interval.

Despite such a wide range of ages for the samples from the same volcanogenic sequences, i.e., the observed disagreement in biostratigraphic and radiologic data, the obtained results are still useful because in most cases they reliably estimate the age of the rocks. One should, however, remember that while considering the age determinations, geologists often choose those data that support their stratigraphical views and dismiss the contradicting ones.

It is a difficult task to separate reliable radiometric data from unreliable ones. During sampling for the subsequent age determination, one should clearly understand all the peculiarities of the geological objects to be analyzed. Thus, one should realize that the Paleogene volcanism was mostly subaqueous in eastern Kamchatka and subaerial in western Kamchatka. However, during the Paleogene and Neogene–Quaternary, volcanic centers often developed discretely for many millions of years; hence, in the case of a co-occurrence of volcanites of similar composition but of different ages, they often are regarded as a single volcanogenic sequence (complex) of a narrow age span.

The analysis of radiological ages of the Cenozoic rocks from Kamchatka shows that it is necessary to properly interpret the setting of collected samples. The setting of collected samples depends on the structure of ancient volcanoes, petrochemical parameters of the pertinent rocks, and the time of their origination.

It follows from the aforesaid that the cited isotopic datings for the Paleogene volcanites of Kamchatka strongly favor an application of the method to interprete the age of volcanic complexes. However, in each case, the data should be considered with care and together with data obtained by other methods. This means that similar investigations should be continued so that

a complex geologic approach can be achieved and truly reliable conclusions made possible.

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REFERENCES

Chelebaeva, A.I. and Shantser, A.E., New Data on the Early Paleogene of Western Kamchatka, *Litologiya i Stratigrafiya Mezozoya i Kainozoya Vostochnykh Regionov SSSR* (Lithology and Stratigraphy of the Mesozoic and Cenozoic of the Eastern Regions of the USSR), Moscow: Nauka, 1988, pp. 135 - 148.

Gladenkov, Yu.B., Bagdasaryan, G.P., Ben'yamovskii, V.N., *et al.*, Paleogene Plankton of the Il'pinskii Peninsula (the Koryak Highland), *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1988, no. 10, pp. 85 - 91.

Gladenkov, Yu.B., Chelebaeva, A.I., Shantser, A.E., *et al.*, New Data on the Paleogene of the Shelekhov Bay Coast (Northwest Kamchatka), *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 6, pp. 7 - 87.

Gladenkov, Yu.B., Sinel'nikova, V.N., Chelebaeva, A.I., and Shantser, A.E., The Problems of the Paleogene in the Tigil' Area, Western Kamchatka, *Korrelyatsiya Kainozoiskikh Tolshch Dal'nego Vostoka* (Correlation of the Far East Cenozoic Deposits), Moscow: Nauka, 1985, Part 1, pp. 45 - 55.

Gladenkov, Yu.B., Sinel'nikova, V.N., Shantser, A.E., *et al.*, *Eotsen Zapadnoi Kamchatki* (The Eocene of Western Kamchatka), Moscow: Nauka, 1991.

Serova, M.Ya., Middle Eocene Planktonic Foraminifers of Western Kamchatka, *Voprosy Mikropaleontologii*, 1969, no. 12, pp. 145 - 166.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 289 - 295. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 92 - 99.
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Geological Interpretation of the Pleistocene Sequences of the Moscow Area Dated by the OSL Method

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Abstract – Geological investigations of the unfossiliferous Pleistocene deposits of the Moscow area, which were dated by optically (infrared) stimulated luminescence (OSL), allow us to define a chronostratigraphic succession of the "barren" glacial formations and to relate them to the interglacial deposits. Some portion of the Mikulino lacustrine strata and peat layers occurs in the Klin–Dmitrov Range area, having been displaced by the Kalinin (early Valdai) glacier in the form of separate blocks. OSL dates of 60 - 65 ka were obtained for the Kalinin glaciation. The blanket deposits, which are related to the periglacial area of the late Pleistocene Ostashkovo glaciation (20 ka), have been studied in a quarry of the Luk'yanovo brick yard near the city of Serpukhov. The blanket stratum lies on the soil, which was formed in the Mikulinian time (100 - 110 ka ago) and was heavily dislocated by the cryogenic processes during a period of 100 to 20 ka. OSL-dating yields the ages of 160 - 170 ka for fluvioglacial sediments of the Moskovian Glacial in Moscow (the Myakinino district) and the town of Dmitrov. These dates correspond to geological evidence. The OSL-date of 196 ka is obtained for the interglacial deposits of the Lipna River sequence near the city of Vladimir, which are assigned to the Odintsovo Horizon. These and other available data form a basis for distinguishing the Odintsovian Interglacial of the middle Pleistocene. The older moraines and fluvioglacial deposits, having an age of 250 - 280 ka, occur near the village of Lipitsy at the Oka River and the town of Lubertsy where they are referred to the Dnieperian Glacial. Further employment of the OSL method is very important for specifying chronostratigraphic schemes and for reconstructing the history of Pleistocene glacial-interglacial cycles.

The Pleistocene geology of the Moscow area attracts the attention of many stratigraphers studying the glacial and interglacial formations in the Russian Plain. A complicated alternation of depositional environments in the peripheral and inner parts of the glacial shields, in the periglacial zones, and during the interglacial periods was ambigouously interpreted. The main differences in view concern approaches to the stratigraphic subdivision and paleogeographic reconstructions of the middle and early Pleistocene. The climatic data based on paleobotanic, mainly palynological records, an inaccuracy in relating, according to the drilling materials, the glacial and interglacial strata with traces of glaciodynamic dislocations, and multivariant paleomagnetic records necessitated a search for new methods to develop a reliable chronostratigraphic scale for the Pleistocene.

Establishing this scale is very important from the view of geological mapping, interregional correlations, and geological prospecting. In this respect, infrared stimulated luminescence dating (the OSL-dating) is very promising, especially for those Pleistocene sequences that cannot be dated by the radiocarbon method and lack fossils. We sampled the middle and upper Pleistocene deposits of different origins (Fig. 1): fluvioglacial and alluvial sands, blanket loams and sandy loams, lacustrine loams, and reworked material from lenses inside the moraines. A major part of these deposits was thoroughly studied geologically; their relations with underlying and overlying strata were established. They were correlated with reference sections in the central Russian Plain.

We will dwell briefly on the principles of the infrared stimulated luminescence dating of the Pleistocene geological objects. Alkali feldspars $K(Na)AlSi_3O_8$, which were extracted from sediments according to a well-known procedure (Hütt and Smirnov, 1983), served as palaeodosimeters. Samples were dated by a technique based on using infrared light for stimulating an informative luminescent signal (Hütt *et al.*, 1988; Hütt and Jaek, 1989a, b, 1990).

The light source used for stimulation was a semiconductor laser IPL-108 with a wavelength emission of approximation 810 ± 0.5 nm. The light beam intensity on the sample was ≈6 mW/cm^2, which corresponds to ordinary sunny day conditions. The laser was operated in pulse mode with a pulse length of 3 s. A shine of this duration and intensity did not cause scintillation of the sample. Repeated laser lightpulses produced signals of initial intensity for the detection of an informative signal (≈400 nm).

The sound regime of stimulation provides for the selection of more light-sensitive grains and does not disturb the stable equilibrium of charge carrier distribution.

The combined OSL/TL method, elaborated at the Institute of Geology of the Estonian Academy of Sciences, was used.

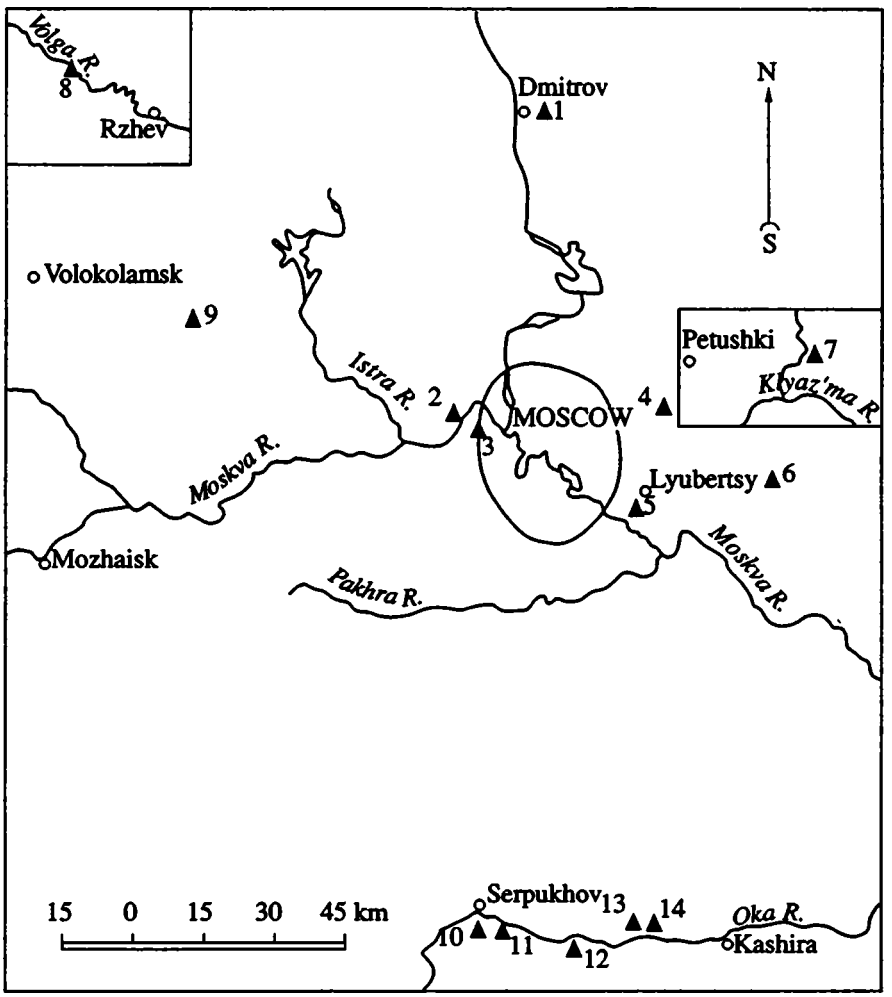

Fig. 1. Schematic map of the Moscow area sequences dated by OSL.

1 – Dmitrov (sequences: "Near the meat-packing plant" and "Borisova Gora" I and II), 2 – Glukhovo, 3 – Myakinino, 4 – sanatorium Krasnaya Roza, 5 – Lyubertsy, 6 – Elektrougli, 7 – Lipna, 8 – Monchalovo, 9 – Novopetrovskoe, 10 – the Luk'yanovo brick-yard, 11 – Lipitsy, 12 – Tul'chino, 13 – Malyushino-1, 14 – Malyushino-2.

The main advantage of optical dating proposed by Huntlet *et al.* (1985), when compared to TL-dating, is the very low residual signal at the moment of sedimentation. In course of the laboratory treatment of a bulk sample by ordinary sunny daylight, the OSL-minimum is reached for 40 - 60 min. In the present study we found that the residual OSL-signal after 45 minutes of sunlight exposure makes up less than one percent of the laboratory saturation signal (in case of the TL-detection of the signal, the corresponding parameter is 25 - 40%). The natural level of feldspar saturation is 2 - 3 times lower than the level reached in the laboratory (Hütt and Jaek, 1989a, b). The high light-sensitivity of the samples suggests that the presedimentation information was well effaced during the deposition with long-time transport.

The OSL-dating technique is as follows. A monomineral fraction of alkali feldspars $K(Na)AlSi_3O_8$ with a grain size of 100 - 160 μm is separated from a bulk sample by analysis in a heavy liquid (density 2.58 ± 2.61 g/cm^3) and subsequently treated by 10% HF to take away the surface α-irradiated layer (D_{ac}). The accumulated dose was reconstructed using the additive dose method and exponential fitting. After irradiation with the gamma-ray source ^{60}Co (~1 Gy/min), the samples were stored at room temperature for three weeks before measurement in order to quench phosphorescence and obtain thermodynamical equilibrium. The dose-rate was calculated from the U, Th, and K concentrations determined by gamma-spectroscopy in the bulk sample with natural humidity. The effect of K (≈10%) on the composition of the paleodosimeters (≈0.35 mGy) and a cosmic component (≈0.15 mGy/year) was taken into consideration as well. The reconstructed accumulated dose and age estimation for one of the samples are shown in Fig. 2 as an example.

At first, a methodical OSL-dating error was estimated to be about 15%. Subsequently, Hütt's dating of the middle and upper Pleistocene deposits decreased this value to 7 - 8%.

The obtained OSL-dates provide a better understanding of the chronostratigraphic succession of moraines, and fluvioglacial and interglacial deposits of the Middle and Late Pleistocene. The dates produced by several samples from the same sequence are of particular interest. So, in the region of the town of Dmitrov (a quarry of the ferroconcrete structures plant), the OSL-dating of the fluvioglacial sand inside the body of the Upper Kalinin moraine (Fig. 3) yields an age of 65 ka (Sample GSL-1108/89). An age of the underlying lacustrine deposits, which were referred to the Mikulinian time by palynological records (Giterman *et al.*, 1978; Moskvitin, 1976), was estimated to be 100 ka (Sample OSL-1109/89). The fluvioglacial sands and sandstones assigned to the Moskovian Glacial have an OSL-age of 160 ka (Sample OSL-1110/89). Thus, an event succession can be established for the period of the end of the Middle Pleistocene to the beginning of the Late Pleistocene. It is also essential that the OSL-dating supports the previous age estimates for the glacial formations of the Kalininian glaciation, terminal moraines of which occur in the Klin–Dmitrov Range. So, OSL-dating, palynological data, and geological control provide evidence of the following: (1) the Kalininian (Early Valdaiian) glaciation was widespread; and (2) the Klin–Dmitrov Range is its southern limit. The Moscow glacial complex correlates well with the fluvioglacial strata of the upper part of the Myakinino Village sequence (Moscow, the ring highway). These strata are commonly assigned to the Moskovian Glacial. Moskvitin considered them as the valley facies of the Moscow moraine. A sample of these deposits produced an OSL-date of 160 ka. The above dates permit correlations with the global oxygen-isotope scale of Shackleton and Opdyke (1976). The date of 100 ka (Sample OSL-1104/89) corresponds to the isotope substage 5e (i.e., Eemian, Sangamonian, Mikulinian, and Kazantsevian Interglacials); the date of 160 ka corresponds to the isotope stage 6 or to the second Middle Quaternary (Varta, Moskovian) Glacial of Europe.

There were some doubts concerning the reality of the Odintsovian Interglacial, which separates the first (Dnieperian) and the second (Moskovian) glacials of the Middle Pleistocene. Together with Yu.M. Vasil'ev, we carried out geological investigations, which allowed us to assign a bed of a whitish loam with ferriferous disseminated particles to the beginning of the Moskovian Glacial or to the terminal stages of the Odintsovian Interglacial. This bed lies under a moraine in the Balashikha Town area, near the sanatorium Krasnaya Roza and has an OSL-age of 170 ka (Sample OSL-1/88). The bed is marked by ochre free designs, pressure traces, and ortsteins indicative of soil-forming processes. It is underlain by a sandy loam with ochre interbeds and interbeds of silting and by a moraine with boulders of local and crystalline rocks.

Studies of the Lipna Village sequence in the area of Vladimir also recovered interglacial deposits and a buried soil under a moraine of the Moskovian Glacial. The

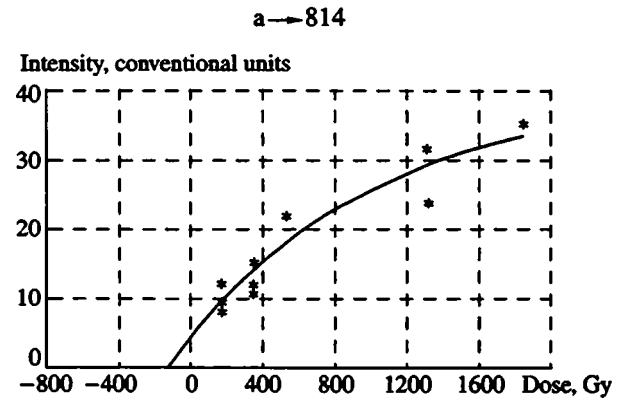

Fig. 2. Reconstruction of the accumulated dose and age estimation by the OSL method.

paleobotanical characteristics of these formations differ much from the interglacial Mikulino and Roslavl' strata. A sample of the interglacial Lipna deposits yields the OSL-date of 196 ka ± 15%. So, these investigations support our earlier suggestion that the studied deposits were formed during the Odintsovian Interglacial and, hence, that this interglacial really occurred.

The older glacial formations were also sampled for OSL-dating. We chose a sequence on a building site – an excavation in a highway crossing at Lipitsy (Fig. 4), on the right bank of the Oka River, at a height of 35 m above the water edge. This sequence, which is located outside the area of distribution of the terminal glacial formations of the Moskovian Glacial, shows a moraine and fluvioglacial sands with pebble and boulders. A sample of the sand strata, which was collected at a height of 0.8 m above the base of the excavation, surely belongs to the reworked part of the moraine, where traces of the quick- and glaciodynamic effect can be observed. The OSL-age of this sample (OSL-1106/89) is 330 ka. A sample of the overlying sand bed with pebble inside the moraine (OSL-1105/89) has an age of 250 ka. The obtained data imply that the fluvioglacial apron is related to the reworking of a moraine of Dnieperian age (330 ka). This period was likely to be the earliest stage of the Dnieperian glaciation. The deposits formed at this stage were dislocated at a later glaciation stage. A sample of sandy-pebbly deposits from the middle part of the road excavation is dated at 250 ka and is referred to the Odintsovian Interglacial and isotope stage 7. This interpretation corresponds to existing Middle Pleistocene chronostratigraphic schemes, which provide an understanding of event succession (Shik, 1992) but cannot be considered as sufficiently accurate with regard to the duration of time-units and ages of boundaries. Specifically, controversial estimates related to the duration of units and the chronological position of stratigraphic boundaries are kept in mind.

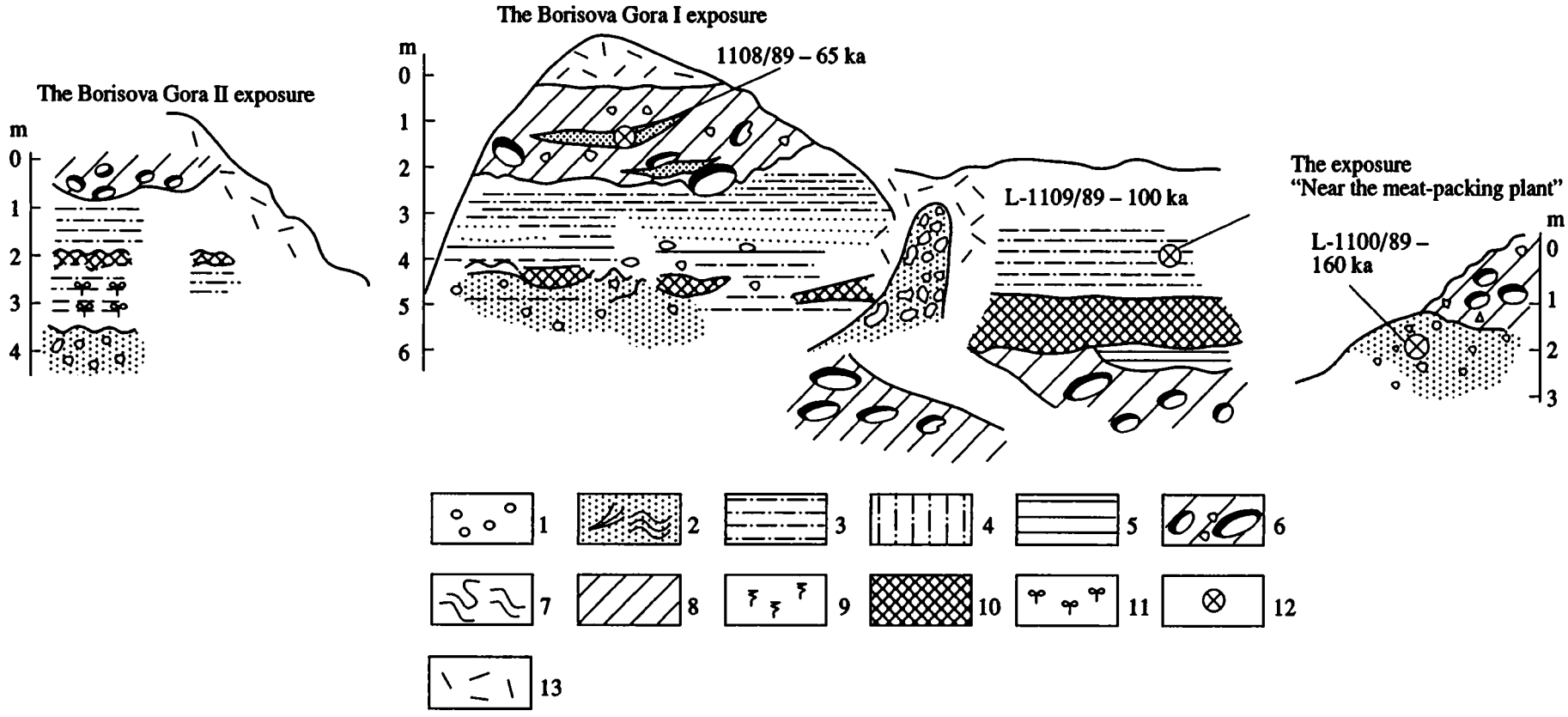

Fig. 3. Relationships between moraines, fluvioglacial, and interglacial deposits in a quarry of Dmitrov.
1 – Pebbles and boulders, 2 – sand, 3 – fine-grained sand and silt, 4 – loesslike loam, 5 – clay, 6 – moraine, 7 – cryogenic dislocations, 8 – fossil soil, 9 – recent soil, 10 – peat, 11 – plant macrofossils, 12 – sites of sampling for the OSL-dating, 13 – taluses.

Perhaps, the glacial deposits of the Dnieperian Glacial were partly reworked (?) later by various processes at the marginal side of the Oka River valley. Samples taken in 1988 from the same excavation, 20 m to the southeast of the place of later sampling, provided an age of 120 ka ± 15% (Sample OSL-4/88) and 190 ka ± 15% (Sample OSL-5/88). The first sample was assigned to the Mikulinian Interglacial, and the second one to the boundary between the Moscow and Odintsovo horizons. These dates indicate the necessity to define geological relationships of the middle and upper Pleistocene deposits on the right bank of the Oka River in additional studies. Therefore, of interest are the materials derived from drilling and investigations in a quarry of the Luk'yanovo brickyard (Fig. 4). The drilling recovered a sandy-pebbly alluvial bed lying on the Carboniferous limestones under a moraine, which can be conventionally assigned to the Dnieperian Glacial. A structure of the lower stratum is similar to the geological relationships at Lipitsy. The hypsometric difference is 25 m. The alluvial series recovered by the well is located at a height of about 60 m above the bank of the Oka River.

Near the Luk'yanovo brickyard, the glacial deposits are overlain by grey clayey silts, which form the blanket stratum comprising the subaerial and possibly lacustrine deposits and fossil soils. The OSL-dating of the soil, 3 m beneath the surface, produced a date of 70 ka (Sample OSL-1115/89, 812), i.e., this soil may correspond to the Amersfortian Stage of Western Europe and isotope stage 5, but it is higher than substage 5e. A date of 100 ka was obtained for a sample of sandy silt from the lower part of the soil (OSL-2/90, 845). The date corresponds to the Mikulinian Interglacial. An age of a sample of the silt bed above the soil is 20 ka (Sample OSL-1/90, 844). Thus, the soil complex recovered in the quarry of the Luk'yanovo brickyard began to form in the first late Pleistocene (Mikulinian, Eemian) Interglacial. Later on, there was an interruption in sedimentation, when the soil was deformed by cryogenic processes. The sedimentation resumed 20 ka ago in the cool late Würm Periglacial.

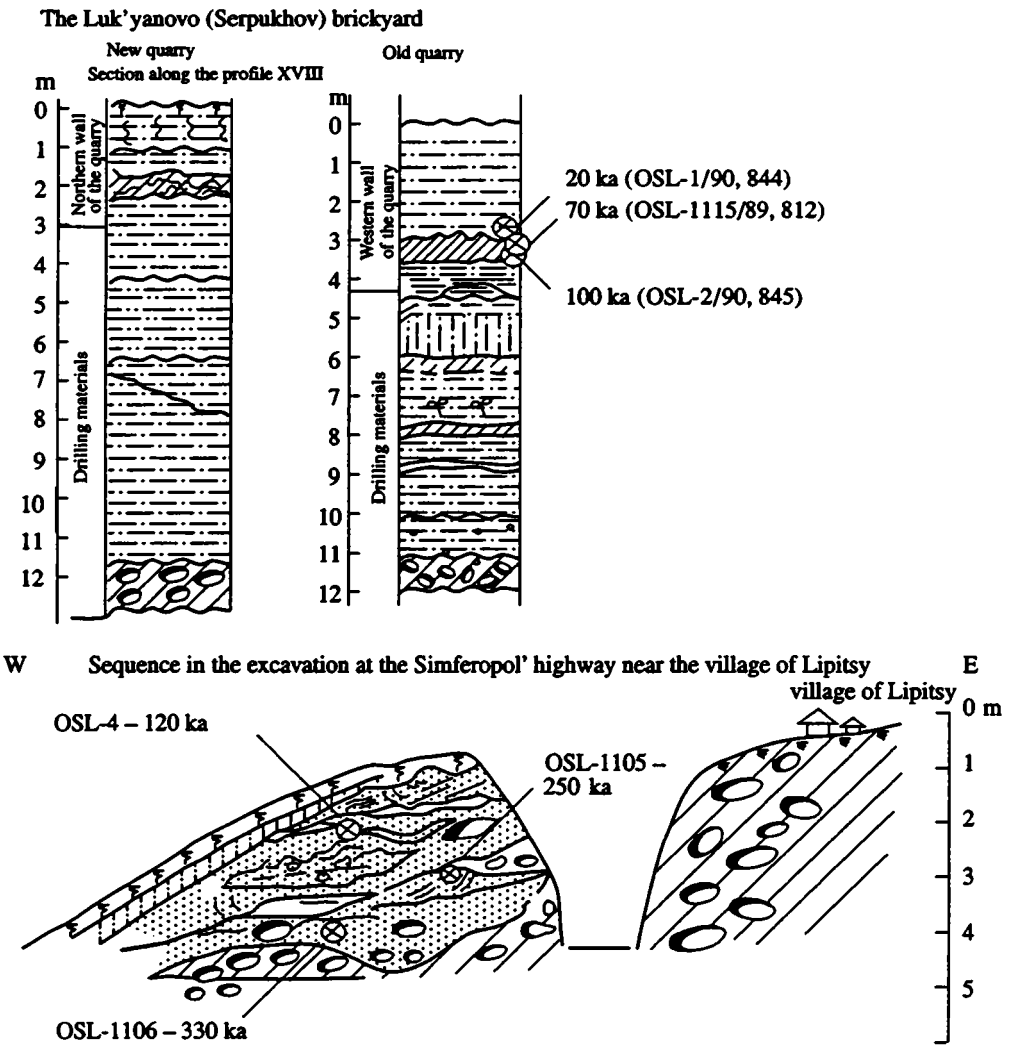

Fig. 4. The Quaternary sequences on the right bank of the Oka River near the village of Lipitsy and in the quarry of the Luk'yanovo brick-yard.

Correlation of the Quaternary deposits of the Moscow area with the European stratigraphic scales

Stratigraphical units		Northern Europe	European part of Russia		Pleistocene sequences of the Moscow area	OSL-dates, ka
Pleistocene	Upper	Weichselian 60 - 65 ka	Ostashkovian Glacial		Luk'yanovo brickyard	20
			Leningradian Megainterglacial			
			Kalininian Glacial		Novopetrovskoe	54
					Borisova Gora	65
			Mikulinian Interglacial	Mezen' complex	Malyushino 1 and 2	65
					Tul'chino	70
		Eemian 130 ka			Luk'yanovo brickyard	70
					Luk'yanovo brickyard	100
					Borisova Gora 1	100
					Lipitsy	120
	Middle	Varta 130 - 200 ka	Moskovian Glacial		Myakinino	160
					Dmitrov quarry	160
		Treene 200 - 250 ka	Odintsovian Interglacial		Krasnaya Roza	170
					Lipna	196
		Drenthe 250 - 300 ka	Dnieperian Glacial		Lipitsy	250
					Lyubertsy	280
		300 ka Holsteinian 440 ka	Likhvinian Interglacial		Lipitsy Lyubertsy	330 300
			Okaian Glacial		Elektrougli	400 (?)

Studies of the alluvial deposits of the Oka River terraces yielded new data on a 9 m terrace sequence. An upper stratum of dark-grey silts containing pollen spectra of the cryophilic vegetation is underlain by the alluvial sediments of the river course facies. The OSL-dates of 70 ka (Sample OSL-1116/89) and 65 ka (Sample OSL-1117/89) were obtained for these deposits near Tul'chino. These alluvial deposits include pollen of a vegetation typical of the warm climate (identifications by L.V. Golubeva). Analogous or similar relationships are peculiar to the lower terrace on the left bank of the Oka River, downstream, near Malyushino.

So, OSL-dating suggests that the lower part of the 9 m terrace sequence in the region of Tul'chino–Malyushino is a base of a younger terrace, alluvium of which was formed in the first half of the late Pleistocene. The date of 65 ka permits assignment of the alluvium to the early warm phase of the Valdaiian Glacial, which probably corresponds to the isotope stage 4.

A unique sequence of glacial deposits near Lyubertsy was chosen for a bed-by-bed description and dating. A quarry exposes a slope of the Lyubertsy elevation located in a plain area, where the outwash sands of the Moskovian Glacial are widespread.

An upper part of the sequence shows fluvioglacial deposits consisting of heavily dislocated sands and silts, which locally form lenses and interbeds penetrating into the underlying moraine. A sample of the sandy sediments (OSL-1111/89) produced an OSL-date of 280 ka, which indicates a Dnieperian age. Two other moraines are recognizable below. Between them there are some pockets and thermokarstic cauldrons filled with sands, gravels, pebbles, and boulders dated as 350 ka (Sample OSL-1113/89). A stratum of lacustrine sands and clays with pebbles can be observed below. A sample from a sand interbed at its base (OSL-1112/89) has an age of about 300 ka. That is, two latter samples characterize the pre-Likhvinian, probably Elsterian (Okaian) time interval.

Sometimes the OSL-dates do not coincide with the age estimates based on previous studies. A quarry in the village of Monchalovo (the Rzhev district, Tver' area) exposes two moraines. An upper moraine covers kames, whereas a lower one lies at the base of them. There is a sandy-pebbly fluvioglacial stratum between these moraines. The OSL dating of the base and top of the stratum (Samples OSL-1101/89 and OSL-1102/89) produced an age of 180 ka, i.e., a series of sediments formed during the Moskovian Glacial has actually been recognized. The interkame filling sediments represent a series of loam–sandy loam with buried soil and peat. A radiocarbon date of 33740 ± 5000 (Sample MGU-1000) was obtained by A.I. Shlyukov for the peat.

These geochronological data suggest some questions concerning the stratigraphic position of the sediments in the Monchalovo sequence. Firstly, can the upper moraine be taken as the Kalininian one? It may

be referred to the Moskovian Glacial. Secondly, the two OSL-dates of 180 ka indicate that these deposits were formed during the Moskovian, not Valdaiian, Glacial. Thirdly, the age of the lower moraine has not yet been specified: the Dnieperian time or older. Fourthly, the Valdaiian time proper is marked by a loam–sandy loam stratum with a peat layer having a radiocarbon age of 33 740 ± 5000 years. The stratum lies in the depression formed as a result of an erosion or glacial exoration.

The OSL method was used to date a uniform sand stratum underlying the fluvioglacial deposits of the Moskovian Glacial on the left bank of the Moscow River, in a quarry near Glukhovo. The sands appeared to be absolutely barren of fossils. No pollen and spores have been found there. The OSL-date for Sample OSL-1103/89 is 360 ka, which permits the standard assignment of this stratum to the Likhvinian Interglacial. But it should be taken into account that the Likhvin deposits occur locally at the base of the terraces in the Moscow River valley.

The outwash sands are widely distributed to the southwest of Moscow, where they stretch toward the Meshchera Lowland. They form a peculiar apron beginning from the marginal part of the Moscow glacier. The OSL-dates for these deposits range between 160 and 200 ka. But there are older sandy strata within the limits of the outwash field. For example, a sample of the sand was collected under the horizon of intensive cryoturbations in a quarry near the city of Elektrougli. According to geological reconstructions, the sample (OSL-1118/89) must belong to the outwash formations of the Moskovian Glacial, but the age determination appeared to be beyond the range of the OSL method, i.e., the sample is much older. If the OSL-dating is correct, this sequence is much older than the Moskovian Glacial and can be assigned to the Okaian Glacial. The formations overlying the sandy stratum may be referred to the Moskovian Glacial, but their age also needs to be defined more exactly.

Another example of significant correction of geological data by means of the OSL-dating is related to the burial of a mammoth skeleton found in 1990, 50 km to the west of Moscow, near the Novopetrovskoe Settlement. Bone-bearing clayey silts and fine-grained sands are overlain there by a bed of sandy-clayey sediments with boulders. The upper bed is interpreted as a moraine of the Moskovian Glacial. The drilling conducted near this locality displayed the same relationships: a moraine overlies a silt-sand stratum.

A date of 54 000 years was obtained for the sandy silt from the bone-bearing bed (Sample OSL-5/90, 848). According to Sulerzhitskii's estimation, the radiocarbon age of the mammoth remains is 45 000 years.

So, the mammoth remains and the sand-silt stratum deposited in the weak drainage basin are younger than the overlying Moscow moraine. The revealed divergence of the geological data and the OSL- and ^{14}C-dates requires further studies of relationships among glacial and lacustrine deposits in the mammoth locality.

Applied to dating of the Pleistocene deposits of the Moscow area, the new method of infrared stimulated luminescence appeared to be very effective (the table), especially when other methods were unsuccessful. The OSL method can be employed for dating fluvioglacial deposits, sand lenses, and interbeds in moraines, as well as the lacustrine sediments and alluvium. Dating of fossil soils and blanket loesslike formations described herein is also of interest. Noteworthy is that the obtained dates, which are well controlled by the geological methods, are in the range of the Middle to Late Pleistocene. Certain limitations relevant to the physical nature of the OSL method prevents dating older geological objects.

The geological interpretation of the OSL-dates allows us to consider the Klin–Dmitrov Range as a reliable limit of distribution of the Kalinin terminal moraines, to prove the correct recognition of the Moscow marginal formations, and to substantiate the occurrence of the Odintsovian Interglacial and the first (Dnieperian) Middle Pleistocene Glacial in the central Russian Plain. In the end, the obtained materials permit correlations of the Middle and Upper Pleistocene units of the Moscow area to the standard continental and oceanic schemes of the Pleistocene.

Reviewer I.I. Krasnov.

REFERENCES

Giterman, R.E., Golubeva, L.V., Koreneva, E.V., Moskvitin, A.I., and Nosov, A.A., The Late Pleistocene Buried Peat Layer in the Town of Dmitrov, Moscow Area, *Bull. MOIP*, 1978, vol. 53, no. 5, pp. 90 - 94.

Huntley, D.J., Godfrey-Smith, D.I., and Thewalt, M.L.W., Optical Dating of Sediments, *Nature*, 1985, no. 313, pp. 105 - 107.

Hütt, G. and Jaek, I., Infrared Stimulated Photoluminescence Dating of Sediments, *Ancient TL*, 1989a, vol. 7, no. 3, pp. 48 - 51.

Hütt, G. and Jaek, I., Photoluminescence Dating of the Alkali Feldspars: Physical Background, Equipment, and Some Results, *Radiation Dosimetry*, 1990, vol. 34, no. 1/4, pp. 73 - 74.

Hütt, G. and Jaek, I., The Validity of the Laboratory Reconstruction of Palaeodose, *Ancient TL*, 1989b, vol. 7, no. 2, pp. 23 - 27.

Hütt, G., Jaek, I., and Chonka, J., Optical Dating: K-feldspars Optical Response Stimulation Spectra, *Quat. Sci. Rev.*, 1988, no. 7, pp. 381 - 385.

Hütt, G. and Smirnov, A., Thermoluminescence Dating of Sediments by Means of the Quartz and Feldspar Inclusion Methods, *PACT*, 1983, no. 9, pp, 463 - 473.

Moskvitin, A.I., *Opornye Razrezy Pleistotsena Russkoi Ravniny* (Reference Sections of the Pleistocene in the Russian Plain), Moscow: Nauka, 1976.

Shackleton, N.J. and Opdyke, N.D., Oxygen-Isotope and Paleomagnetic Stratigraphy of Pacific Core v. 28 - 239. Late Pliocene to Latest Pleistocene, *Bull. Geol. Soc. Am.*, 1976, vol. 145, pp. 449 - 464.

Shik, S.M., Problems of the Pleistocene Stratigraphy of the East European Platform, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1992, no. 1, pp. 3 - 10.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 296 - 301. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 100 - 106.
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Evolution of the biosphere

Late Pliocene–Pleistocene Paleogeography and Geological Events in Middle Asia

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Abstract – Analysis of biotic and abiotic events in Middle Asia revealed the main trends in paleoenvironmental evolution. An attempt to reconstruct the paleoclimatic and paleoenvironmental conditions in the Late Pliocene and Pleistocene is made, based on the paleoecologic study of mammalian faunas and palynologic data. Short-term paleoclimatic oscillations were recorded in the loess–soil sequence. Regional phases of tectonic uplift in the Middle Asian mountains resulted in aridization of intermontane depressions.

The most complete paleogeographic information on such a geologically complicated region as Middle Asia is available mainly for piedmont and intermontane troughs filled up with thick Upper Cenozoic sequences, where loess–soil covers are widespread. Mammalian remnants occurring there are vital in paleogeographic and paleoecologic reconstructions. The loess–soil sections are another important source of information, which suggests the key to understanding paleoclimatic oscillations during the last 2 Ma. The paleotectonic analysis is rather useful in elucidating the general trend of paleoclimatic changes. Archeological localities in fossil soils provide data on the ecology of ancient man and significantly supplement paleogeographic records. The complex analysis of biotic and abiotic events is a solid basis for paleoenvironmental reconstructions.

There are several regions in Middle Asia with reference sections of Upper Pliocene–Quaternary sediments: (1) Kuruksai, Lakhuti, Khonako, Chashmanigar, Kairubak, Karamaidan, and other sections in the Tadzhik Depression; (2) Kairakkum and Sokh in the Fergana Depression; (3) Orkutsai in the Tashkent region; and (4) Dzhilgyndykoo, Akterek, and Tepke in the Issyk-Kul' Depression. Taking into account the variety of geological objects and the polygenetic character of the Upper Pliocene–Quaternary deposits paleontologic, geologic, geomorphologic, paleomagnetic, paleopedologic, and archeologic methods were used to solve stratigraphic and paleogeographic problems. We distinguish large stratigraphic subdivisions, both the formations and groups, corresponding to the Upper Pliocene (3.5 - 1.8 Ma), Eopleistocene (1.8 - 0.8 Ma), and Pleistocene (0.8 Ma), and smaller climatostratigraphic units (the loess and paleosoil horizons). The latter correspond to glacial and interglacial events, which were most distinct during last 0.8 Ma (the figure).

Three biostratigraphic levels corresponding to the Middle Villafranchian, and Early and Late Galerian of the European continental scale are well characterized paleontologically.

In southern Tadzhikistan the earliest biostratigraphic level is represented in the Kuruksai locality, where the rich and diverse fauna was studied. *Equus stenonis bactrianus*, *Dicerorhinus* cf. *etruscus*, *Megantereon megantereon*, *Homotherium crenatidens*, *Ursus etruscus*, *Archidiscodon* cf. *gromovi*, *Paracamelus praebactrianus*, *Gazella parasinensis*, and other forms were identified there. The Kuruksai assemblage is correlated with the Middle Villafranchian fauna of Europe (*Biostratigrafiya* ..., 1988). According to paleomagnetic data, the major faunal horizon of Kuruksai lies within the reversely magnetized interval in the lower part of the Matuyama epoch below the Olduvai event (Pen'kov *et al.*, 1976). This permits us to date the biostratigraphic level as approximately 2 Ma.

The Karamaidan, Zil'fi, Obigarm, and Tutak localities in the northern Tadzhik Depression yield similar fauna. These localities were thoroughly studied in recent years, and their faunas were shown to occur in a relatively short stratigraphic interval within the Middle Villafranchian and to correlate with the Kuruksai fauna (Dodonov *et al.*, 1991).

In the Issyk-Kul' Depression, north Tien Shan, Late Pliocene fauna is known from the Dzhilgyndykoo and Akterek sections. In the Dzhilgyndykoo locality, the Upper Issyk-Kul' Subformation deposits yield remains of *Leporinae* gen., *Ochotonoides* cf. *complicidens*, and *Promimomys* ex gr. *stehlini* (identified by Zazhigin). In

the Akterek deposits of the same subformation *Struthio transcaucasicus, Dicerorhinus* sp., and *Gazellospira* sp. were found. Additionally, the Upper Pliocene sediments of other two Issyk-Kul' localities, Ordokuchar and Ichketasma, yield finds of *Archidiscodon meridionalis* and *Equus stenonis*, respectively (Dmitrieva and Nesmeyanov, 1982).

Remnants of *Archidiscodon meridionalis meridionalis, Dicerorhinus* sp., and *Elasmotherium* sp. (identified by Belyaeva, Dubrovo, and Reshetov) were found in the C_2 Formation, the Kairakkum section of the western Fergana depression. According to Dubrovo, *Archidiscodon meridionalis meridionalis* remains are related to the archaic form of the southern elephant and correspond to a faunal evolutionary stage not younger than the Khapry mammalian assemblage.

A paleomagnetic study of bone beds in the Kairakkum locality, made by Eroshkin, indicated that faunal remains were deposited at the boundary between sediments of normal and reversed polarity, which was interpreted as the Gauss–Matuyama reversal (Tetyukhin *et al.*, 1980).

As evidenced by the foregoing, the Kuruksai assemblage is the richest and most diverse among the Late Pliocene faunal localities known in Middle Asia. Paleoecological analysis of the Kuruksai faunal composition made it possible to reconstruct the Late Pliocene paleoenvironments. Inhabitants of dry open landscapes, i.e., representatives of *Ellobius, Pachycrocuta, Chasmaporthetes, Paracamelus*, and *Equus* were the most characteristic members of the mammalian assemblage. *Gazella parasinensis* inhabited the steppes, *Protoryx* and *Gazellospira* populated shrubby savannas, whereas the antelope *Damalops* lived in savannas with thick herbaceous vegetation (*Biostratigrafiya* ..., 1988; Dmitrieva, 1977). Among deer, the genera *Sinomegaceros* and *Eucladoceros* were distributed within areas of more or less open landscapes, whereas *Axis* inhabited hilly woodlands not far from water. The rest of the Kuruksai deer lived in the forest, as *Libralces*, and, evidently, in swamp biotopes, as *Elaphurus* (Vislobokova, 1990). Bears and primates (genus *Paradolichopithecus*) may have inhabited mountain forests.

Palynologic records significantly supplement the data on the mammalian fauna. Thus, the palynoflora of the Kuruksai bone bed yields the forest forms presently absent in Tadzhikistan: *Pinus, Abies, Cedrus, Quercus, Tilia, Corilus*, and others. The pine, evidently *Pinus longifolia*, now inhabiting the Hindu-Kush, was common on mountain slopes. The presence of linden, hazel, and oak may indicate a more humid climate. The tugai vegetation occurred in river valleys. Open landscapes were occupied by a semisavanna vegetation cover (Ovchinnikov and Baiguzina, 1977; *Putevoditel'* ..., 1977).

Therefore, the analysis of palynologic data together with paleoecological study of the fauna showed the mosaic structure of paleolandscapes and distinct altitudinal zonation. Mountain ranges covered with forest were combined with piedmont plains where open dry territories prevailed, along with tugai and swamp areas.

The younger stratigraphic level is represented in the Lakhuti-2 bone bed, southern Tadzhikistan, and in the Tepke-1 locality, Issyk-Kul' depression. The thoroughly studied bone bed of Lakhuti-2 yielded *Ellobius* sp., *Microtus* sp., *Cletrionomys* sp., *Meriones* sp., *Canis lupus* cf. *mosbachensis, Xenocyon lycaonoides, Pachycrocuta brevirostris, Homotherium* sp., *Panthera gombaszoegensis, Archidiscodon* sp., *Equus* aff. *namadicus, Sinomegaceros* sp., *Praemegaceros* sp., *Camelus knoblochi*, and other forms. Beds, enclosing the fauna, are reversely magnetized and occur several meters lower than the Matuyama–Brunhes reversal. The mammalian fauna from Tepke beds has the same geological position. In the Tepke-1 locality, the reversely magnetized loams and loamy sands from the lower part of the Tepke Mountain section contain remnants of *Equus* ex gr. *sanmeniensis, Cervus* sp., *Bison* sp., *Pachycrocuta* ex gr. *brevirostris*, and *Canis* cf. *lupus* (identified by Belyaeva and Motuzko).

The analysis of the mammalian assemblage from the Lakhuti-2 locality allows the reconstruction of the Early Pleistocene faunal evolutionary stage in Tadzhikistan. The composition of this assemblage differed significantly from that of Kuruksai, but its ecological parameters were to some extent similar to the latter. Like in Kuruksai, it yielded inhabitants of forest and flood-plain sites, though the forms of open steppe landscapes dominated. Palynologic data on the Lakhuti section (after Ershova – *Putevoditel'* ..., 1977) confirm the results of the paleoecologic analysis of mammalian fauna. According to Pakhomov's palynologic data, paleoenvironments of that age were characterized by mixed landscapes with mountain slopes covered by coniferous and broad-leaved forests, while piedmont plains were areas of forest-steppe or steppe vegetation (Ranov *et al.*, 1987).

Paleozoogeographical study and comparison of the Kuruksai and Lakhuti faunas revealed a significant difference between them. The Villafranchian fauna from Tadzhikistan is attributed to a separate East Mediterranean province of the Mediterranean subregion. It was a mixture of Mediterranean and Central Asian components, and the similarity to Mediterranean forms is notable at the specific level. The influence of the Indo-Malayan zoogeographic region was insignificant due to the high mountains between Hindustan and Middle Asia, which served as a biogeographic barrier to direct faunal exchange (*Biostratigrafiya* ..., 1988).

Species widespread within the Palaearctic dominated the Lakhuti-2 fauna, along with forms typical of the Central Asian areas or those from the western Palaearctic. Lakhuti-2 is the single Eurasian locality of overlapping distribution areas of the European (*Praemegaceros*) and Asian (*Sinomegaceros*) large-antler deer. On the whole, the Lakhuti-2 fauna had a distinct Palaearctic character. Unlike the Kuruksai fauna, which is dominated by Mediterranean forms, the

Lakhuti-2 assemblage was much more influenced by the fauna of the European-Siberian subregion. A more intensive influence on faunas from southern subregions began in the Late Villafranchian, as it was recorded by Vangengeim (Vangengeim and Pevzner, 1991).

The youngest reference biostratigraphic level was recognized in the Dzhirgalan Formation, Tepke section. Here, in the Tepke-2 bone bed, 15 m below the top of the section, small mammals *Sorex* sp., *Ochotona* sp., *Clethtionomys* sp., *Microtus* ex gr. *gregaloides*, and *Microtus* sp. were found. According to Zazhigin, the fauna is dated as the end of the early or the beginning of the Middle Pleistocene. Additionally, the bed with rodent bone remains yielded an antler fragment of *Cervus* cf. *accoronatus* (identified by Vislobokova). Finds of *C. accoronatus* are unknown in deposits younger than the Lower Pleistocene. Therefore, the sediments enclosing the Tepke-2 bone bed also cannot be younger. Another important argument supporting the Early Pleistocene age of the enclosing deposits is a find of an elephant tooth fragment 6 m below the bed with rodent bone remnants. In Dubrovo's opinion, the tooth fragment most likely belongs to the Early Pleistocene *Mammuthus trogontherii trogontherii*.

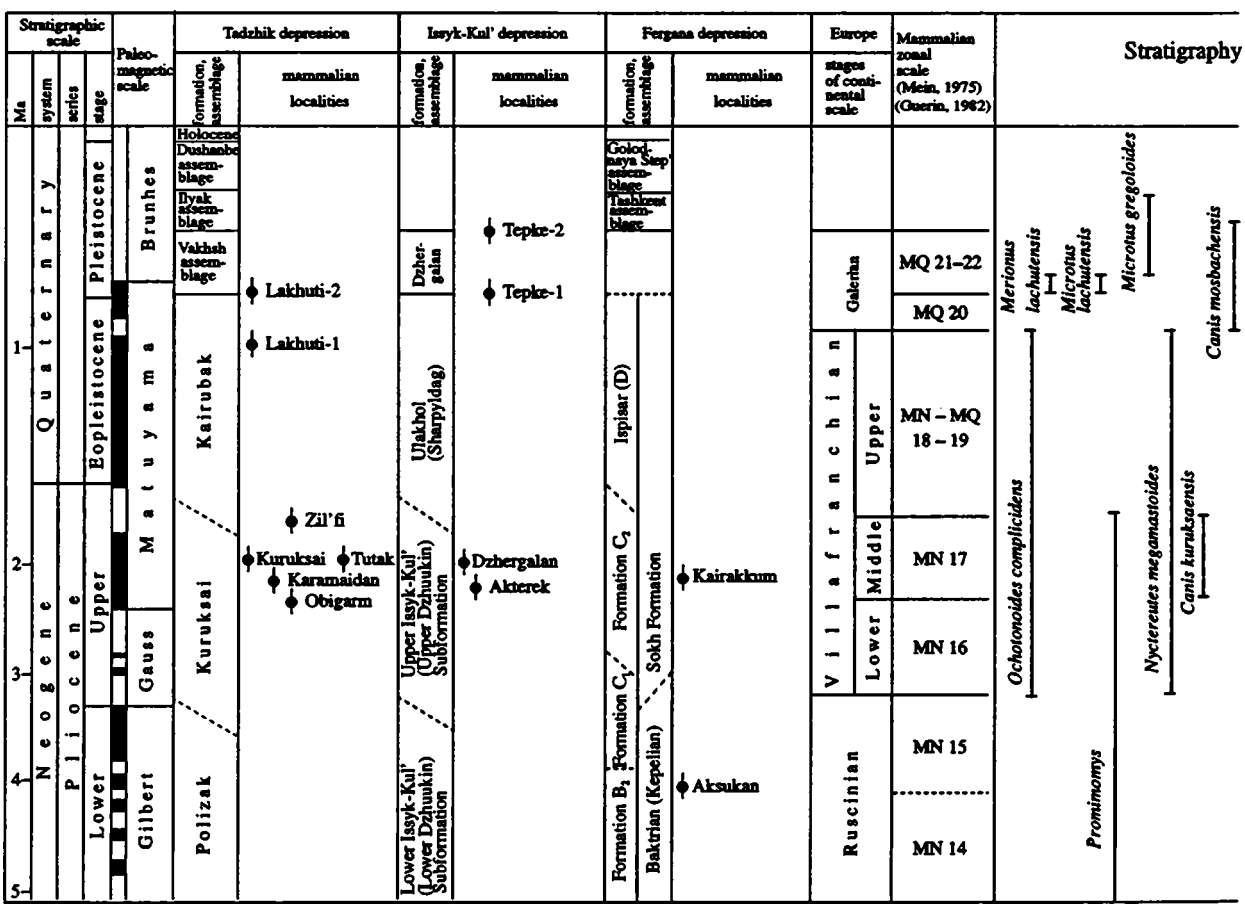
According to paleomagnetic data, the Tepke-2 bone bed lies within the normally magnetized interval above the Matuyama–Brunhes reversal.

Spore and pollen analysis of deposits of the Dzhirgalan Formation indicates relatively arid conditions in the period of their accumulation. The increased number and diversity of arborescent and shrub pollen corresponds to the higher than present afforestation of mountain slopes (*Razrez noveishikh otlozhenii* ..., 1971).

Unfortunately, deficient paleontological data precludes more definite conclusions on the paleogeographic environment of that time. It is only possible to suggest that some faunal taxa from the Tepke-2 locality were widespread in Eurasia in the first half of the Pleistocene.

Along with the analysis of biotic events, we studied the abiotic factors and, primarily, the formation of loess-soil cover, as well as the paleotectonic events.

The Middle Asia tectonic phases were most distinct at the Early-Late Pliocene, Late Pliocene–Eopleistocene, and Eopleistocene–Pleistocene boundaries, as well as during the Late Pleistocene (Dodonov, 1978, 1986). Geologic data on the northern regions of India, Pakistan, and China shows the correlation of tectonic activity phases with those in Middle Asia (Liu Tungsheng,



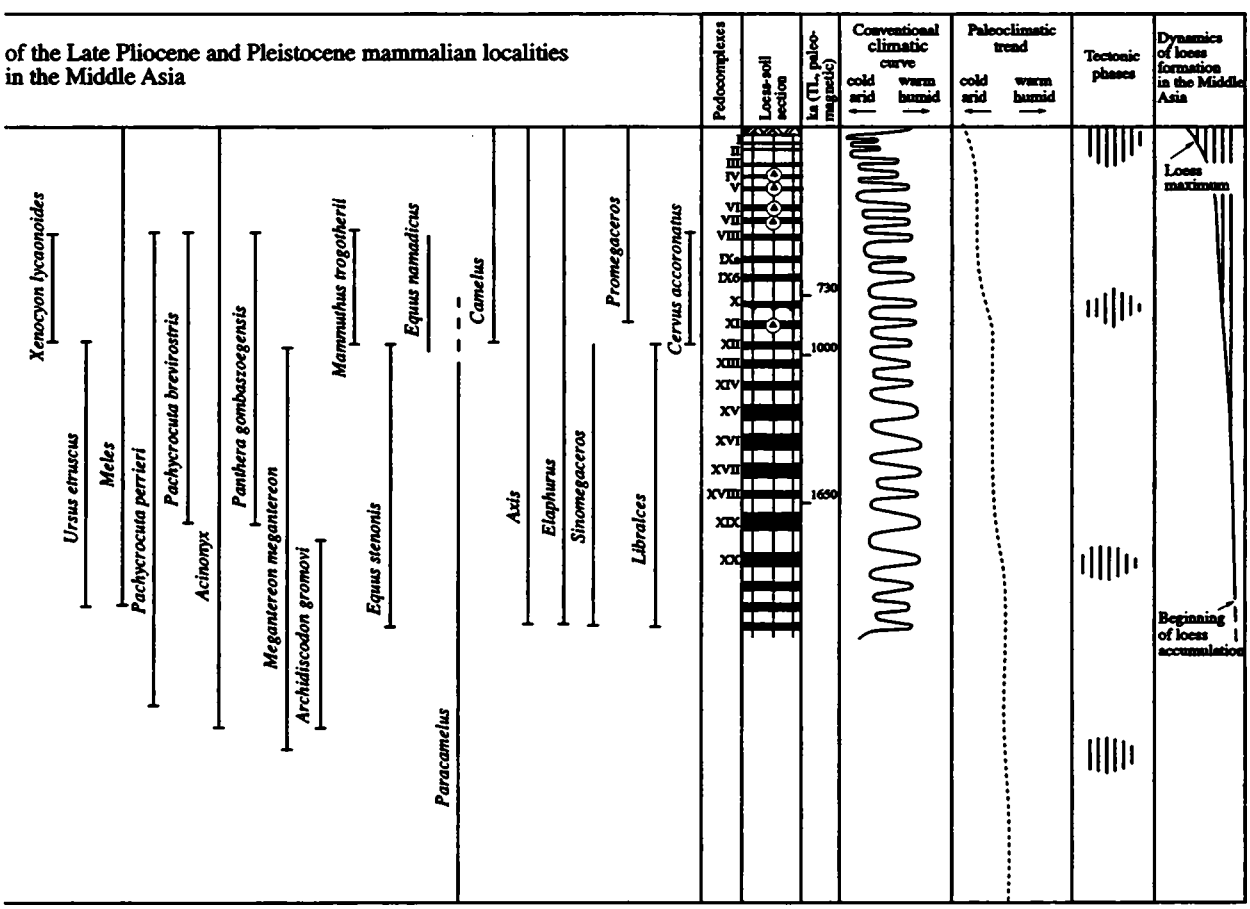
Stratigraphy of the Late Pliocene and Pleistocene mammalian localities in the Middle Asia and geologic events.

1986; Burbank and Johnson, 1982, 1983; Burbank and Raynolds, 1984; Li Jijun, 1991). The tectonic uplifts resulted in high mountain glaciations and widening of a periglacial zone in the mountains. This initiated the production of abundant silty material in the nival zone. The material was then transported by water to piedmont plains, where it experienced deflation and wind transportation to slopes and piedmont watershed areas, forming loess covers. Deserts surrounding the Middle Asian mountains were another source of silty particles. The thickness of loess covers in piedmont areas of the Pamirs and Tien Shan ranges from several dozens of meters to 100 - 200 m.

The initiation of loess-forming processes signified the onset of an essentially arid climate of a continental type. In Middle Asia it was the result of the mountain uplift and increased isolation of piedmont and intermontane depressions from the influence of humid air masses. Taking into account the data on the age of ancient loesses in Middle Asia, China, northern Pakistan, and Kashmir Valley (Dodonov, 1986; Liu Tungsheng, 1985; Agrawal *et al.*, 1988; Rendell, 1988), we can see a certain relation between loess-forming stages associated with the aridization of paleoclimate and tectonic activity phases. Thus, the most ancient loess horizons in Middle Asia and China were recorded in the Late Pliocene. The loess accumulation occurred in the Eopleistocene and increased in the Pleistocene, especially in its terminal part. Due to the increasing loess formation at the Middle-Late Pleistocene boundary, the Kashmir Valley, Peshawar basin, and Potwar Plateau also became loess-accumulating regions.

During the Upper Pliocene and Pleistocene intervals, loess sections of Middle Asia incorporated a lot of red, red-brown, and brown soils. Up to 10 red and red-brown paleosoils occur below the Olduvai event. In the Eopleistocene, 25 horizons of red-brown and brown soils were recorded. They are conventionally combined into nine pedocomplexes (PC), namely, XI - XIX.

Ten pedocomplexes and the same number of loess horizons were distinguished within the Pleistocene section. Brown and grey paleosoils of mountain forests were recorded in that stratigraphic interval (Lomov, 1989). The mountain-forest brown soils are characteristic of the XIII, VII, VI, V, and IV PC. The light-brown carbonate soils are associated with the III and II PC. The X, VII, VI, and V PC serve as the regional reference horizons. They were dated by means of paleomagnetic and thermoluminescence methods, which were supplemented by archeologic records. Archeologic localities associated with the XI, VI, V, and IV PC correspond to the pebble culture of the Premousterian



time, i.e., they are older than 70 ka (Dodonov and Ranov, 1984).

The process of subaerial sedimentogenesis had a distinctly cyclic character. Loess horizons alternate with fossil soil beds and each of them has its specific features. A high clay content, leaching, and presence of carbonate crusts, as well as the ferrugination (high Fe_2O_3 + FeO content and high Fe_2O_3/FeO coefficient) in developed Pleistocene fossil soils of the section, indicate the intensive paleopedogenetic processes associated with optimum paleotemperatures and humid paleoenvironments. All data considered, we can suggest with sufficient confidence the association of intensive soil-forming phases with optimum climatic conditions corresponding to certain interglacial or interstadial events. Researchers who studied fossil soils of the Loess Plateau in northern China (Liu Tungsheng, 1985; Liu Tungsheng and Yuan Baoyin, 1987; Guo Zheng Tang, 1990) and Kashmir Valley (Bronger *et al.*, 1987) came to the same conclusion.

Palynologic study of loess-soil covers by Pakhomov, Ershova, Baiguzina, and Bolikhovskaya showed a general trend of climate aridization toward more continental environments from the Eopleistocene to the terminal Pleistocene. Some of the studied sections, e.g., XI, X, VII, VI, and V PC, have individual palynologic characteristics, namely, the predominance of arborescent vegetation and a decrease in herbaceous plants. The composition of arborescent vegetation indicates a rather humid and mild climate. At the same time, the paleosoil and loess palynospectra are not always easily distinguished. The only palynologic data on such sections are insufficient for reconstruction of paleoclimatic events. Possibly, the result of pollen input from the deflation zone (eolian genesis of loesses) changed the local spectra composition. Moreover, we should take into account that paleosoils developed on loesses, therefore, different palynocomplexes of "soil" and "loess" type to a certain degree are superimposed. Finally, we cannot exclude the role of bioturbation in soils, which also results in the formation of mixed palynocomplexes.

Analysis of all the data on loess–soil sections in Middle Asia was used to plot a curve representing short-term paleoclimatic oscillations. In general, the oscillations correspond to the analogous paleoclimatic events reconstructed according to loess sections in China (Liu Tungsheng, 1985), or glacial-interglacial and loess sequences in Europe (Velichko, 1991; Kukla, 1978), as well as with the oxygen-isotope variations curve (Shackleton and Opdyke, 1976). The exact correlation of certain paleoclimatic events depends on the availability of geochronologic data for a section. The studied loess–soil sequences showed the presence of 20 dry-cold and humid-warm intervals during last 0.75 Ma. Therewith, warm intervals often consisted of several optimums.

Paleolithic sites associated with fossil soils were studied in southern Tadzhikistan (Dodonov *et al.*, 1978; Ranov *et al.*, 1987). These studies defined the age of Paleolithic in Middle Asia to be at least 0.8 Ma. It is significant that Paleolithic remains within the loess horizons proper are hitherto unknown in sections of Middle Asia. This evidently suggests that optimum climatic conditions for ancient man were during soil-forming periods. During the loess accumulation, floral and faunal impoverishment and deterioration of climate, namely, aridization, severe winters, and frequent sand storms resulted in the migration of ancient people from loess regions. It is believed that such migrations were recurrent.

Accordingly, the study of paleoecosystems of the Late Pliocene to the terminal Pleistocene interval showed that in piedmont areas of Middle Asia, the climate changed from warm, unevenly moistened with relatively low oscillations of seasonal temperatures, to a more cool and arid climate with a higher temperature gradient between warm and cold seasons. It is important that in the Pleistocene, the temperature decrease during cold seasons had the most significant influence on general climatic cooling. Short-term paleoclimatic oscillations, the most distinct in the Pleistocene, resulted in soil and loess formation and were characterized by extreme variations of temperature and humidity.

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REFERENCES

Agrawal, D.P., Juyal, N., Sharma, P., Gardner, R., and Rendell, H., Paleogeography of the Loess Deposits of Kashmir, *Palaeoclimatic and Palaeoenvironmental Changes in Asia during the Last 4 m.y.*, New Delhi: Indian National Sci. Acad., 1988, pp. 51 - 57.

Biostratigrafiya Pozdnego Pliotsena–Rannego Pleistotsena Tadzhikistana (Late Pliocene–Early Pleistocene Biostratigraphy of Tadzhikistan), Petrov, O.M., Ed., Moscow: Nauka, 1988.

Bronger, A., Pant, R.K., and Singhvi, A.K., Pleistocene Climatic Changes and Landscape Evolution in the Kashmir Basin, India: Paleopedologic and Chronostratigraphic Studies, *Quaternary Res.*, 1987, no. 27, pp. 167 - 181.

Burbank, D.W. and Johnson, G.D., Intermontane-Basin Development in the Past 4 m.y. in the Northwest Himalaya, *Nature*, 1982, vol. 298, no. 5873, pp. 432 - 436.

Burbank, D.W. and Johnson, G.D., The Late Cenozoic Chronologic and Stratigraphic Development of the Kashmir Intermontane Basin, Northwestern Himalaya, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1983, vol. 43, pp. 205 - 235.

Burbank, D.W. and Raynolds, R.G.H., Sequential Late Cenozoic Structural Disruption of the Northern Himalayan Foredeep, *Nature*, 1984, vol. 311, no. 5982, pp. 114 - 118.

Dmitrieva, E.L., *Antilopy Neogena Mongolii i Sopredel'nykh Territorii* (Neogene Antelopes of Mongolia and Adjacent Areas), Moscow: Nauka, 1990.

Dmitrieva, E.L. and Nesmeyanov, S.A., *Mlekopitayushchie i Stratigrafiya Kontinental'nykh Otlozhenii Yugo-Vostoka Srednei Azii* (Mammals and Stratigraphy of Continental Sed-

iments in the Southeastern Middle Asia), Moscow: Nauka, 1982.

Dodonov, A.E., Late Pliocene–Quaternary Stage of Tectogenesis in Tadzhik Depression, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1978, no. 10, pp. 72 - 84.

Dodonov, A.E., *Antropogen Yuzhnogo Tadzhikistana* (Anthropogene of Southern Tadzhikistan), Moscow: Nauka, 1986.

Dodonov, A.E. and Ranov, V.A., Anthropogene of the Middle Asia: Stratigraphy, Correlation, Paleolithic, *Doklady 27 Mezhdunarodnogo Geologicheskogo Kongressa, Sek. C.03, Chetvertichnaya Geologiya i Geomorfologiya* (Reports of 27th Int. Geol. Congr., Sec. C.03, Quaternary Geology and Geomorphology), Moscow: Nauka, 1984, vol. 3, pp. 67 - 81.

Dodonov, A.E., Ranov, V.A., and Pen'kov, A.V., Paleolithic Findings in Ancient Fossil Soils of Southern Tadzhikistan and Their Geologic Position, *Bull. Komis. Izuch. Chetv. Per.*, 1978, no. 48, pp. 86 - 102.

Dodonov, A.E., Zhegallo, V.I., Pen'kov, A.V., and Sotnikova, M.V., Stratigraphy of the Late Pliocene Vertebrate Localities in Southern Tadzhikistan, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1991, no. 5, pp. 12 - 21.

Guo Zheng Tang, Succession des paleosols et loess du centre-ouest de la Chine: approche Micromorphologique, *Thése de Doctorat de L'Université Paris*, 1990.

Kukla, G., The Classical European Glacial Stages: Correlation with Deep-Sea Sediments, *Trans. Neb. Acad. Sci.*, 1978, vol. 6, pp. 57 - 93.

Li Jijun, The Uplift of the Qinghai-Xizang Plateau and Its Effect on Environment, *Quaternary Geology and Environment in China*, Beijing: Science, 1991, pp. 265 - 272.

Liu Tungsheng, *Loess and the Environment*, Beijing: China Ocean, 1985.

Liu Tungsheng, Success in the Quaternary Research of China, *Issledovaniya Chetvertichnogo Perioda* (Quaternary Research), Moscow: Nauka, 1986, pp. 53 - 64.

Liu Tungsheng and Yuan Baoyin, Paleoclimatic Cycles in Northern China (Luochuan Loess Section and Its Environmental Implications), *Aspects of Loess Research*, Beijing: China Ocean, 1987, pp. 3 - 26.

Lomov, S.P., Pleistocene–Holocene Soils and Soil Covers of the Pamirs-Alai, *Doctorate (Geol.-Min.) Dissertation*, Moscow: Mos. Gos. Univ., 1989.

Ovchinnikov, P.N. and Baiguzina, L.L., On the Palynologic Characteristic of Upper Pliocene Deposits in the Kuruksai River Basin (Southern Tadzhikistan), *Dokl. Akad. Nauk Tadzhik. SSR*, 1977, vol. 20, no. 8, pp. 64 - 66.

Pen'kov, A.V., Gamov, L.N., and Dodonov, A.E., Composite Paleomagnetic Section of Upper Pliocene–Pleistocene Sediments in the Kyzylsu River Basin (Southern Tadzhikistan), *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1976, no. 9, pp. 33 - 43.

Putevoditel' Ekskursii (Guide-Book of Excursions), Dodonov, A.E., Melamed, Ya.R., and Nikiforova, K.V., Eds., Int. Symp. "Neogene–Quaternary Boundary," Moscow: Nauka, 1977.

Ranov, V.A., Dodonov, A.E., Lomov, S.P., Pakhomov, M.M., and Pen'kov, A.V., Kul'dara, the New Lower Paleolithic Memorial of Southern Tadzhikistan, *Bull. Komis. Izuch. Chetv. Per.*, 1987, no. 56, pp. 65 - 75.

Razrez Noveishikh Otlozhenii Issyk-Kul'skoi Vpadiny (Sequence of Recent Deposits in the Issyk-Kul' Depression), Markov, K.K., Ed., Moscow: Mos. Gos. Univ., 1971.

Rendell, H.M., Environment Changes during the Pleistocene in the Potwar Plateau and Peshawar Basin, Northern Pakistan, *Palaeoclimatic and Palaeoenvironmental Changes in Asia during the Last 4 m.y.*, New Delhi: Indian National Sci. Acad., 1988, pp. 58 - 66.

Shackleton, N.J. and Opdyke, N.D., Oxygen-Isotope and Paleomagnetic Stratigraphy of Pacific Core V28-239, Late Pliocene to Latest Pleistocene, *Geol. Soc. Am. Mem.*, 1976, vol. 145, pp. 449 - 464.

Tetyukhin, G.F., Eroshkin, A.F., and Popov, V.I., On the Boundary of the Neogene–Quaternary Deposits in Uzbekistan, *Granitsa Neogena i Chetvertichnoi Sistemy* (Neogene–Quaternary Boundary), Moscow: Nauka, 1980, pp. 208 - 215.

Vangengeim, E.A. and Pevzner, M.A., Villafranchian in the USSR: Bio- and Magnetostratigraphy, *Paleogeografiya i Biostratigrafiya Pliotsena i Antropogena* (Paleogeography and Biostratigraphy of the Pliocene and Anthropogene), Moscow: Nauka, 1991, pp. 124 - 145.

Velichko, A.A., Correlation of Late Pleistocene Events in Glacial Regions of the Northern Hemisphere, *Bull. Komis. Izuch. Chetv. Per.*, 1991, no. 60, pp. 14 - 28.

Vislobokova, I.A., *Iskopaemye Oleni Evrazii* (Fossil Deers of Eurasia), Moscow: Nauka, 1990.

Stratigraphy and Geological Correlation, Vol. 2, No. 3, 1994, pp. 302 - 306. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 2, No. 3, 1994, pp. 107 - 112.
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BRIEF COMMUNICATIONS

Floral Assemblages at the Eocene–Oligocene and Early Miocene Boundaries in West Siberia

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Abstract – The urgency of research evaluating geologic events and, first of all, the floral changes occurring in the Eocene through Oligocene and in the Early to Middle Miocene, is evident. At that time considerable changes in biota associated with climatic variations occurred throughout the vast continental and oceanic areas. At the end of the Eocene in West Siberia the epicontinental basin dried up, and continental sedimentation began.

This event corresponded to the global climatic cooling that resulted from the Drake Strait opening, the isolation of the Antarctic from warm oceanic waters, and the formation of glacial cover.

The development of the dinocyst zonal scale for the West Siberian Paleogene (Kul'kova and Shatskii, 1990) permitted the improvement of sediment dating (the table). Due to the presence of dinocysts in spore and pollen assemblages, marine and continental sediments were correlated. The dinozone age determinations were correlated with the nannoplankton and dinocyst zonal stratigraphy from southern provinces of the former USSR studied by Andreeva-Grigorovich (1991). Within the West Siberian Lowland, namely in the Severnaya Sos'va River basin, in the Chuzik and Kenga rivers upper courses (the Ob'–Irtysh interfluve), and along the Ivdel'–Ob' railway in the Vasyugan River basin, lower beds of the Upper Tavda Subformation yield dinocyst assemblages with the Priabonian zonal form *Charlesdowniea clathrata angulosa*. The *Ch. clathrata angulosa* Zone corresponds to nannoplankton zones NP18 - NP20. Cavate dinocysts *Deflandrea phosphoritica, Charlesdowniea clathrata angulosa, Ch. clathrata, Wetzeliella articulata*, and *Gochtodinium* are characteristic of the assemblage, though they are not numerous. Chorate forms are represented mainly by *Areosphaeridium*, a few *Cordosphaeridium*, *Spinifirites*, and others. The assemblage is more impoverished than the Bartonian complex of the Lower Tavda Formation, which yields *Kisselovia ornata, Rhombodinium pentagonum, Wetzeliella irtishensis, Lentinia serrata, Areosphaeridium dictyoplocus, Wetzeliella articulata, Spinifirites, Cordosphaeridium*, and other microphytoplankton taxa. Voszhennikova and Oleinik (1988) noted that the microphytoplankton taxa decrease in abundance in the Upper Eocene sediments of West Siberia. Reduction of the West Siberian sedimentary basin was different in northern and southern regions. This is a result of the uplift of northern regions and the separation of the West Siberian sea from northern basins. The Turgai Strait connected the sea with the Mediterranean basin (Shatskii, 1978). The Late Tavda basin was shallow with calm hydrodynamic conditions, which favored the accumulation of thin-foliated clays. Both the regression and freshening of the basin led to further change and impoverishment of microphytoplankton assemblages. The top beds of the Upper Tavda Subformation deposits yield rare specimens of the zonal form *Charlesdowniea clathrata angulosa*, together with *Deflandrea phosphoritica, Microdinium*, and *Wetzeliella*. Among the acritarchs *Schepelevia, Veryhachium*, and *Mycrhistridium* were found. The green algae *Chrassosphaera* and *Pterospermella* occur here more often, and the appearance of numerous remains of the water-fern *Hydropteris indutus* Kond is very characteristic. Other data on similar changes in the dinocyst composition at the Eocene–Oligocene boundary are also available (Andreeva-Grigorovich, 1991; Voszhennikova and Oleinik, 1988; Sharafutdinova, 1984). These changes were associated with the World Ocean regression at the Eocene–Oligocene boundary. A study of the Eocene and Oligocene palynocomplexes in West Siberia enabled the recognition of floral changes on the continent. Thermophilic Eocene floras are important stratigraphic markers, and the study showed the gradual disappearance of certain thermophilic species from the floral assemblages. The Late Eocene palynofloras from West Siberia were studied a great deal and are well known (Lyubomirova, 1976; Panova *et al.*, 1990; Aleksandrova, 1979; Volkova *et al.*, 1990; and others). These floras are well correlated and give evidence that by the Late Eocene, the amount of plants producing small tricolpate pollen similar to the ancient evergreen oaks *Quercus gracilis, Q. graciliformis*, and *Tricolpopollenites liblarensis*, was increasing in Siberian floras. These representatives of Fagaceae are the Upper Eocene index forms not only for West Siberia, but also for sediments of the same age in northern Kazakhstan (Volkova and Kul'kova, 1980) and for the Belaya Glina Horizon in the Crimean Bakh-

Paleogene zonal scale of West Siberia according to dinocysts

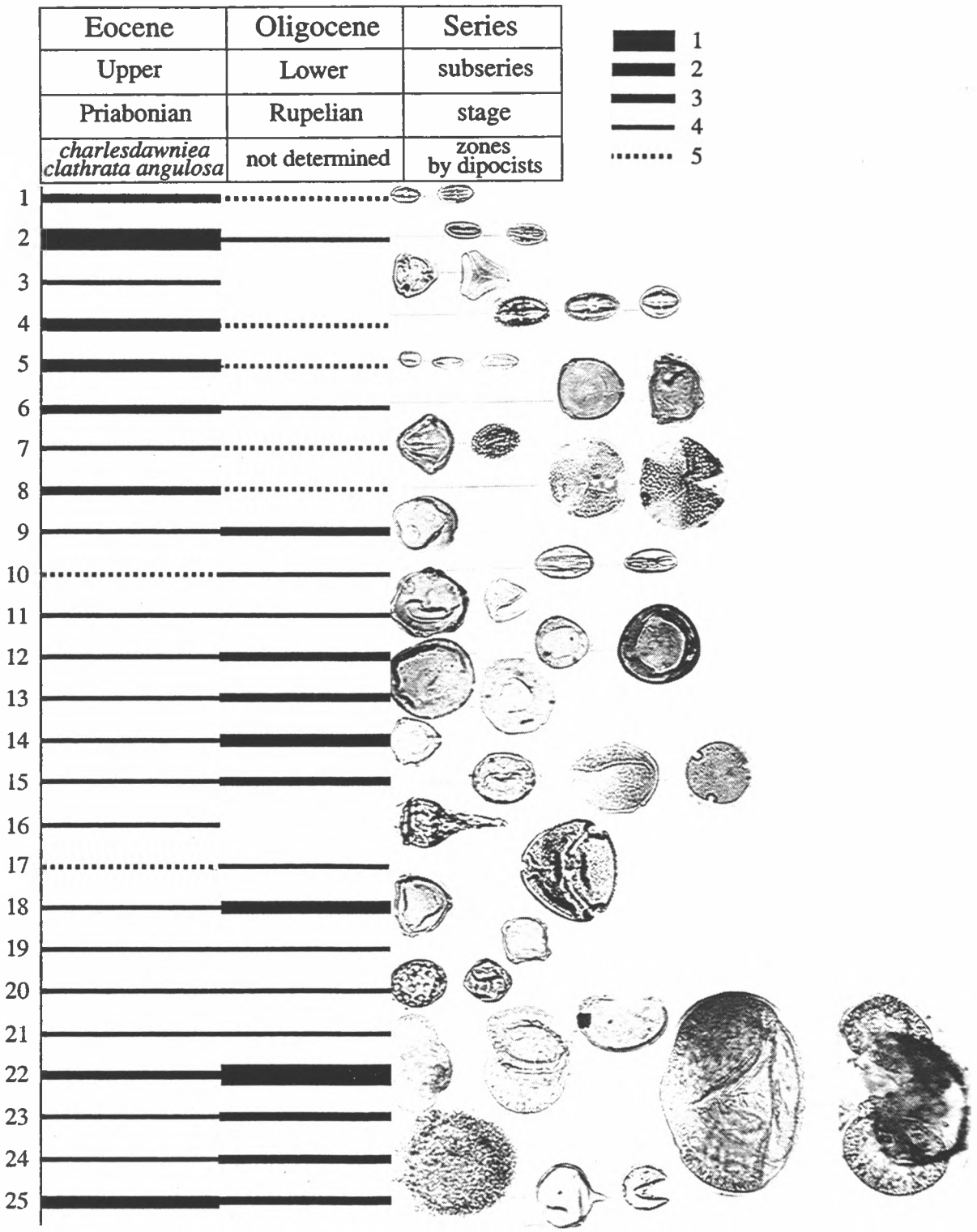
Series	Subseries	Stage	Martini, 1971	Paleogene unified zonal scale of the southern USSR (Andreeva-Grigorovich, 1990)		Regional zonal scheme of West Siberia (Kul'kova, 1991)	Formations
Oligocene	Lower	Rupelian	NP23				
			NP24	*W. gochtii*		n.d.	Atlym
			NP21	*Westzeliella symmetrical/ P. amoenum*			
Eocene	Upper	Priabonian	NP19/20	*Charleadowniea clathrata angulosa*		*Ch. clathrata angulosa*	Tavda
			NP18				
	Middle	Bartonian	NP17	*Rhombodinium porosum*		*Kisselovia ornata W. irtischensis A. dictyoplocus*	
			NP16	*Dracodinium intermedium A. diktyoplokus*			
		Lutetian		*Rhombodinium draco/ Wetzrliella articulata*		n.d.	Nyurol'
			NP15	*Charlasdowniae colleothrypta rotundata*	*Chariesdowniea coleothrypta* s.l.	*Charlesdowniea tenuivirgula*	
			NP14			*Ch. coleothrypta rotundata Ch. coleothrypta*	
	Lower	Ypresian	NP13				
			NP12	*Ch. coleothrypta*			
			NP11	*Dracodinium varielogi-tudum*		*D. varielongitudum D. similis*	Irbit
				D. similis			
			NP10	*Wetzeliella meckelfel-densis*		*W. meckelfeldensis*	
Paleocene	Upper	Thanetian	NP9	*Apectodinium homomorphum*		*A. homonorphum*	Serov
			NP8				
			NP7				
			NP6	*Cerodinium speciosus*		*Cerodinium speciosum Cerodinium markovae*	Talitsa
	Lower	Montian	NP5				
			NP4				
		Danian	NP3	*Cerodinium striatum*			
			NP2	*Carpatella cornuts*			
			NP1				

chisarai sequence (Panova *et al.*, 1990). Along with the evergreen oak pollen, the Upper Eocene assemblage includes the tricolporate pollen of *Castanea, Castanopsis, Aralia, Rhus, Nyssa*, and *Sterculia*, though its role decreased as compared to the Middle Eocene, and at the end of the Late Eocene become insignificant. The thermophilic Juglandaceae taxa, such as *Engelhardtia, Cyclocarya*, and *Platycarya*, gradually disappeared as well, whereas the generic diversity of mesophilic Juglandaceae (*Juglans, Carya*, and *Pterocarya*) and Ulmaceae plants increased. The thermophilic families Sapindaceae, Loranthaceae, Cyrilaceae, and Palmae progressively dropped out of the Late Eocene flora. The Late Tavda flora yielded all recent families and most genera of mesophilic broad-leaved and parvifoliate plants, though they played a minor role in the floral composition. Pinaceae and Taxodiaceae dominated among the Late Tavda conifers, whereas cryptogamous plants, namely, Polypodiaceae, *Osmunda, Lycopodium*, and *Gleichenia*, were rare. This floral composition indicates a climatic cooling.

By the Early Oligocene, a period of intensive tectonic activity, a regression of marine Tavda basin occurred, and the West Siberian craton became a vast lacustrine-alluvial plain, i.e., a large basin of continental sedimentation (Shatskii, 1978). This stage in the development of the West Siberian Lowland was associated with a planetary transformation of climatic and tectonic regimes. The regression of the Paleogene epicontinental West Siberian basin resulted in a complete disappearance of the marine taxa and changed the continental biota. The Atlym Formation sediments, unconformably overlying those of the Tavda Formation, accumulated at that time. The Early-Middle Oligocene (first half) age of the Atlym Formation was established based on the correlation of its palynocomplexes with those of the Ashcheairyk Formation from the northern Ustyurt Plateau (Zhezhel', 1973), which yielded a rich assemblage of Rupelian age (Korobkov, 1965).

The Atlym time in West Siberia was a period in which mesophilic deciduous arborescent plants from Betulaceae, Juglandaceae, Ulmaceae, Fagaceae, and others families flourished. These were the species *Betula gracilis* Pan., *Betula* spp., *Carya spackmania* Trav., *Juglans polyporata* (Vojcel), *J. siboldianiformis* Vojcel., *Pterocarya stenopteroides* Vojcel., *Pterocarya* spp., *Carpinus perfectus* Pan., *Corylus sibirica* Pan., *Alnus* spp., and various species of *Liquidambar, Tilia, Ilex*, and *Nyssa*. Typical Eocene forms *Castanea, Castanopsis, Quercus gracilis*, and *Q. graciliformis* were still retained in assemblages as relics. The Atlym floras were characterized by abundant conifers with dominant Taxodiaceae and diverse forms of *Pinus genus*, i.e. *P. cembraeformis riciformis* Zakl., *P. strobiformis* Zakl., *P. longifoliiformis* Zakl., *P. sibirica*, along with the less abundant, *Tsuga, Abies, Picea, Podocarpus*, and *Cedrus*. Undershrub and water-swamp plants *Diervilla* spp., Ericaceae, *Sparganium*, and *Potamogeton* occurred there as well. Cryptogamous forms of Polypodiaceae (*Osmunda, Lycopodium*, and *Gleichenia*) were rare and not diverse. The pollen and spore assemblage of the Atlym Formation persistently contains *Carya spackmania*, and is variable in composition. In northern regions of West Siberia the assemblage yielded *Myrica, Betula*, and *Juglans*, whereas *Carpinus* and *Liquidambar* prevailed in the south. Pinaceae, which occupied high terraces, and Taxodiaceae, widespread in depressions, were abundant everywhere. Therefore, the turning-point of floral evolution at the Eocene–Oligocene boundary, i.e., the replacement of subtropical "Poltava" assemblages by mesophilic "Turgai" flora (the figure), is clearly observed in the West Siberian Paleogene. This event is recognized by many palynologists and manifested in different ways in various regions. In Lower Oligocene palynocomplexes of the Crimea and Caucasus (Panova *et al.*, 1990), Pinaceae and broad-leaved Juglandaceae become more diverse, whereas subtropical forms are less abundant. In Armenia (Panova *et al.*, 1990) the corresponding assemblages yield an increased amount of xerophytic subtropical pollen of Eleagnaceae, Bombacaceae, and Malvaceae. At the beginning of the Early Oligocene, forests of northeastern Russia were similar to the Turgai type, though with the presence of *Alnaster* and *Betula* sect. Nanae (Fradkina, 1988). Kartashova *et al.*, (1987) also recorded this pollen type in the Oligocene flora of the northeastern province, though at the same time it includes such genera as *Pterocarya, Carpinus, Corylus, Fagus*, and *Myrica*, which require rather high temperatures and are ecologically incompatible with *Alnaster* and *Betula* sect. Nanae. This combination of pollen in the Oligocene floras of northeastern Russia is notable and deserves further investigation. It may possibly be the result of a dissected topography or some other causes as yet unknown. Floral changes in West Siberia indicate a climatic cooling at the beginning of the Oligocene that resulted in drastic alterations of the land flora and a disappearance of dinocyst owing to the marine basin regression. However, the cooling at the Eocene–Oligocene boundary in West Siberia was less than in the Northeast (Kartashova *et al.*, 1987) and Far East of Russia.

Another turning-point in the Paleogene–Neogene evolution of West Siberian flora was associated with the Early-Middle Miocene boundary. At this boundary many representatives of the Turgai flora that appeared at the beginning of the Oligocene and flourished in the Late Oligocene (Turtas time) became extinct. At the beginning of the Miocene, in the Abrosimovo time, the flora was very similar to that of the Turtas period, though its impoverishment is already notable: pines became less diverse, but parvifoliate forms (*Betula, Corylus*) more abundant. However, the broad-leaved forms *Quercus sibirica* Pan., *Celtis, Ulmus, Planera, Tilia, Carya*, and *Pterocarya* were still numerous. The amount of undershrubs and herbaceous plants increased. As a whole, that was the beginning of the new, Neogene evolutionary stage of the West Siberian vegetation.



Change of palynocomplexes at the Eocene–Oligocene boundary in West Siberia.

1 – *Castanea, Castanopsis*; 2 – *Quercus gracilis*; 3 – *Pompeckjoidaepollenites, Loranthus*; 4 – *Rhoipites, Tricolporopollenites*; 5 – *Tricolpopollenites*; 6 – *Comptonia, Myrica, Triatripollenites*; 7 – *Nyssa, Ilex*; 8 – Hamamelidaceae; 9 – *Liquidambar*; 10 – *Quercus*; 11 – *Pterocarya, Platicarya*; 12 – *Carya, Carya spakmania*; 13 – *Juglans polyporata, Juglans siboldianiformis*; 14 – *Corylus, Carpinus*; 15 – *Ulmus, Zelkova, Tilia*; 16 – *Hydropteris indutus*; 17 – *Fagus*; 18 – *Betula*; 19 – *Alnus*; 20 – Herbaceous and shrub plants; 21 – Spores; 22 – *Pinus* n/pH and n/pD; 23 – *Abies, Picea, Podocarpus*; 24 – *Tsuga*; 25 – Taxodiaceae.

Abundance: 1 – abundant; 2 – common; 3 – few; 4 – rare; 5 – isolated finds.

The most drastic changes in the West Siberian flora occurred at the Early-Middle Miocene boundary. The *Alnus*–Polypodiaceae assemblage from the Beshcheul' Horizon sediments is referred to the Middle Miocene. This Beshcheul' flora includes the Kozhevnikovo, the Late Kireevo, and the proper Beshcheul' assemblages.

As compared to the Early Miocene flora, which evidently corresponded to the Miocene optimum, the Kozhevnikovo time was characterized by an abrupt decrease in Juglandaceae abundance, namely, of their genera *Carya, Pterocarya*, and *Juglans*. At that time, the amount of Betulaceae, such as *Corylus* and *Carpinus*, as well as subtropical *Ilex* and *Nyssa* decreased, but *Betula* and *Alnus* became more numerous, while *Fagus, Quercus*, and *Ulmus* still were common.

By the Late Kireevo time the number of *Juglans, Quercus, Ulmus*, and *Fagus* species diminished still further. *Cryptogamous* forms, especially, Polypodiaceae, became more abundant, and by the Beshcheul' time pollen of *Alnus* and spores of Polypodiaceae began to dominate the assemblage. Broad-leaved *Fagus, Quercus, Ulmus*, and *Juglans* were scarce, similar to *Ilex* and *Nyssa*. The quantity of water-swamp plants rose.

Accordingly, in the Neogene we can trace the species evolution, extinction of exotic forms, and the appearance of new taxa and floral assemblages. In the Beshcheul' time, coniferous and broad-leaved forests of the Turgai type were replaced by parvifoliate vegetation, which included mainly *Pinus* and more rare *Abies, Picea*, and *Tsuga* as representatives of conifers, and scarce broad-leaved *Quercus, Fagus*, and *Ulmus*. The period is remarkable due to coenoses of riparian and meadow-steppe plants, which were later on widely distributed in Neogene floras.

So, palynologic study of the Paleogene and Neogene sediments in the West Siberian Lowland enabled us to distinguish two major turning points in flora evolution.

At the first turning point corresponding to the Eocene–Oligocene boundary the Late Eocene subtropical flora was replaced by the Oligocene mesophilic vegetation of the Turgai type. At this level microphytoplankton disappeared due to the drying out of epicontinental West Siberian sea and climatic change.

The second turning-point corresponds to the Early-Middle Miocene boundary. By that time the new, Neogene, stage of the floral evolution began. Broad-leaved and coniferous-hardwood forests gave way to those of a more temperate type with coniferous assemblages and steppe coenoses.

Reviewer L.A. Nevesskaya.

REFERENCES

Akhmet'ev, M.A., Volobueva, V.I., Gladenkov, Yu.B., and Sheludchenko, S.D., Late Paleogene Cooling in the Eastern USSR according to Paleobotanic Data, *Byull. MOIP, Otd. Geol.*, 1986, vol. 61, no. 4, pp. 87 - 100.

Aleksandrova, L.V., Palynologic Grounds for the Eocene–Early Miocene Stratigraphy of Tomsk–Ob' Region, *Stratigrafiya i Palinologiya Mezozoya i Kainozoya Sibiri* (Mesozoic and Cenozoic Stratigraphy and Palynology of Siberia), Novosibirsk: Nauka, 1979, pp. 99 - 144.

Andreeva-Grigorovich, A.S., Paleogene Zonal Stratigraphy in the Southern USSR (Dinocysts and Nannoplankton), *Doctorate (Geol.-Min.) Dissertation*, L'vov: Gos. Univ., 1991.

Fradkina, A.F., Palynology of Paleogene and Neogene in Northeastern Asia, *Palinologiya v SSSR* (Palynology in the USSR), Novosibirsk: Nauka, 1988, pp. 134 - 139.

Kartashova, G.G., Arkhangelov, A.A., and Pirumov, L.G., Oligocene Cooling in Northern Yakutiya (Kolyma River Lower Reaches), *Klimaty Zemli v Geologicheskom Proshlom* (Earth Climates in Geological Past), Moscow: Nauka, 1987, pp. 165 - 179.

Korobkov, A.I., Stratigraphy of Oligocene Deposits according to Mollusks from Northern Ustyurt and Northern Aral Region, *Cand. Sci. (Geol.-Min.) Dissertation*, Leningrad: Vsesoyuzn. Geol. Inst. (VSEGEI), 1965.

Kul'kova, I.A. and Shatskii, S.B., Zonal Subdivision of Marine Paleogene of the West Siberian Plain according to Dinocysts, *Geol. Geofiz.*, 1990, no. 1, pp. 25 - 31.

Lyubomirova, K.A., Palynologic Characteristics of Chegan Horizon in Northwestern Siberia, *Palinologicheskie Issledovaniya* (Palynologic Research), Leningrad: VNIGRI, 1976, pp. 33 - 48.

Panova, L.A., Gromova, N.S., and Maligonova, E.Yu., Palynostratigraphy of Paleogene Sediments, *Prakticheskaya Palinostratigrafiya* (Practical Palynostratigraphy), Leningrad: Nedra, 1990, pp. 149 - 179.

Sharafutdinova, N.G., Microphytoplankton Distribution in Paleogene Deposits of Northeastern Turgai Trough, *Sreda i Zhizn' na Rubezhakh Epokh Kainozoya v Sibiri i na Dal'nem Vostoke* (Environments and Life in Siberia and the Far East at the Cenozoic Boundaries), Novosibirsk: Nauka, 1984, pp. 103 - 106.

Shatskii, S.B., Major Problems on Paleogene Stratigraphy and Paleogeography of Siberia, *Paleogen i Neogen Sibiri* (Paleogene and Neogene of Siberia), Novosibirsk: Nauka, 1978, pp. 3 - 21.

Volkova, V.S. and Kul'kova, I.A., Palynologic Grounds for Stratigraphic Subdivision and Correlation of Paleogene–Neogene Continental Sediments in Southwestern Siberia and Northern Kazakhstan, *Paleopalinologiya Sibiri* (Paleopalynology of Siberia), Moscow: Nauka, 1980, pp. 65 - 73.

Volkova, V.S., Kul'kova, I.A., and Fradkina, A.F., *Eocene Climate in Siberia (West Siberia as the Example)*, Novosibirsk: Nauka, 1990, pp. 1 - 28.

Voszhennikova, T.F. and Oleinik, E.S., Planktonic Paleoalgafloras of Cenozoic from the Southern USSR, *Palinologiya v SSSR* (Palynology in the USSR), Novosibirsk: Nauka, 1988, pp. 139 - 143.

Zhezhel', O.N., On the Problem of the Eocene-Oligocene Boundary in Northern Ustyurt Sediments, an Implication from Paleopalynologic Data, *Palinologicheskii Metod v Stratigrafii* (Palynologic Methods in Stratigraphy), Leningrad: Vsesoyuzn. Geol. Inst. (VSEGEI), 1973, pp. 180 - 184.

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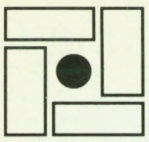

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